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ADVANCED FIRE PROTECTION DELUGE SYSTEM PHASE I REPORT

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13. ABSTRACT *(Maximum 200 words)*

This project involved the development and testing of an ultra high speed fire protection deluge system for U.S. Army Ammunition Plants. The system was capable of detecting and extinguishing munition fires in milliseconds. A prototype system was built using dual band IR and combination UV/IR optical fire detectors, high speed pressurized water discharged from 10L and 30L spheres, and follow-on pressureized water from standard nozzles as found in existing plant and arsenal systems.

The prototype system was tested for fire detection and suppression with 1/4 to 1/2 lb samples of eight different pyrotechnic compositions. They ranged from benign to very energetic compositions including smoke, first fire, illumination mixes and IR decoy flare mix. Each material was tested with each of the four detectors. Approximately 100 total evaluations were accomplished in Phase I. The three dual band optical detectors and the UV detector were also subjected to extensive false alarm stimuli testing. These stimuli included floodlights, flashlights, neon drop lights, sunlight, chopped light (flood light and drop light sources), drill motor (with sparks), and MIG and stick welding (mild steel, aluminum, stainless steel) with various currents and rods.

Data was directly measured from observations recorded on a 1000 frame per second high speed camera and a data recorder. Data recorded included: detectable event, detector alarm, sphere discharge time, sphere water on hazard flame time, follow-on water discharge and fire suppression time.

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EXECUTIVE SUMMARY

A. OBJECTIVE

The objective of this program was to develop and demonstrate an advanced ultra high speed fire protection deluge system that will provide a 95% reduction in false alarms caused by ultraviolet (UV) emissions, provide a 75% reduction in response time compared to current systems installed at Army ordnance facilities and will extinguish each of the pyrotechnic materials tested.

B. BACKGROUND

Energetic materials which burn or deflagrate pose a significant risk to munitions production, maintenance and renovation operations, as reflected by losses suffered by the U.S. Army Armament Munitions and Chemical Command (now Industrial Operations Command) between 1988 and 1992. These costs totaled $9,500,000 and involved three deaths, nine serious injuries, and severe property damage. Contractors, working on similar materials, under contract to the Department of Defense suffered an additional four deaths and severe property damage since 1991. Non-quantifiable costs included legal, environmental, investigations, lost production, and mandated improvements.

In Army ordnance facilities, fire detection and suppression systems have not fully kept up with advances in new technologies. Many existing ultra high speed deluge systems are not optimally designed and installed. Such problems have been identified and documented by accident investigation teams, surveys, staff assistance visits and project reviews. Also, false alarm system activations have occurred with serious impact on ordnance operations. Further complicating the existing situation is the lack of standardization guidance, performance standards and the loss of personnel qualified to design, install, and maintain ultra high speed deluge systems. In mid 1992, the U.S. Army Defense Ammunition Logistics Activity at the suggestion of the U.S. Army Industrial Operations Command approached the Wright Laboratory Fire Research Section at Tyndall Air Force Base, Florida, to examine a joint approach to solving speed, effectiveness and false alarm problems with high speed deluge fire protection systems.

C. SCOPE

This project involved the development and testing of an ultra high speed fire protection deluge system capable of detecting and extinguishing munitions fires in milliseconds. A prototype system was built using dual band IR and combination UV/IR optical fire detectors, high speed pressurized water discharged from 10L and 30L spheres, and follow-on pressurized water from standard nozzles as found in existing plant and arsenal systems. The pressurized water for these follow-on nozzles was supplied from a 400 gallon tank capable of being pressurized to 300 psi. The detectors represent state of the art units currently used in military armored vehicles and tanks. The units can be activated within 3-5 milliseconds and are advertised by the manufacturers as being virtually free of false alarm activation. Testing of the detectors under realistic false alarm stimuli was an important facet of this project.

A prototype system was built and set up in a remodeled existing test facility at Tyndall AFB FL that is capable of supporting explosive testing. Preliminary testing with gasoline soaked sand and gunpowder confirmed that the system could "see" and react quickly enough to extinguish a fast propagating fire. Actual munitions material could not be obtained before formal testing started because of the tight controls and accountability placed on the production and handling of such material. Formal testing commenced in January 1996 and over 100 "burns" have been accomplished with 8 different pyrotechnic materials obtained from the U.S. Army plants and arsenal assembly lines that will eventually use this system. These tests included samples ranging in size from 1/4 lb to 1/2 lb. Larger amounts of pyrotechnic materials and some propellants will be tested against the system as part of Phase II of the project.

D. RESULTS

1. Each of the eight (8) pyrotechnic materials burned without detonation when placed in a small pile on the test table (1/4 to 1/2 lb samples).

2. The advanced fire protection deluge system was able to detect and successfully extinguish each burning material for every test burn accomplished. This was true with each of the four detectors used to activate the system, although some detectors were faster than others for a particular material burn.

3. The new detector and sphere deluge system responds to M206 in 8 milliseconds (ms) on average (6 ms average detector response and 2 ms average sphere discharge response). The current standard for ultra high speed water suppression systems is NFPA 15 which requires 100 ms response time "for system operation from the presentation of an energy source to the detector to flow of water from the water spray nozzle being tested."[1] The energy source mentioned is not defined in the standard however for this discussion it is considered to be equivalent to a saturated ultraviolet energy source. This is best demonstrated in our tests by the M206 Flare Composition reaction. This material propagates when burning at an average rate of 10 inches per millisecond.

Testing found that currently installed Detector Electronics (Det Tronics) detectors, control panel and pilot operated solenoid water valve systems can respond in 36 ms after a fire detector activation when the air is properly bled from the supply lines. The control panel and sphere deluge system developed in this program respond in two milliseconds after a fire detector activation. Also, the water velocity is much greater for the new deluge system. After exiting the nozzle, water reaches the burning material 36 inches away in 18 ms compared to 90 ms after exiting the nozzle for the existing system.

4. The sphere water provided enough cooling to quickly and effectively control and extinguish the burning munitions for the materials and quantities tested in this program. Although pressurized follow-on water was present in each deflagration test, it was not required to control and extinguish the burning pyrotechnic material.

E. CONCLUSIONS

(Note: It is important to understand the following when evaluating test results and conclusions.)

Detector response times were measured from the detectable event (the time that the initial fire was visible on the high speed camera) until the detector alarmed. The resulting times are directly related to the rate of flame growth for each individual material. Using the definition mentioned above from NFPA 15, response time is measured as the time from the presentation of a saturated UV source to the detector until the detector alarms. In these Phase I tests, a fire emitting enough energy to be defined as a saturated UV source occurred on very few occasions and only with M206 IR Flare Composition. Most of the fire alarms were realized after the fire grew to a point where it emitted the minimum radiation required for a detector to alarm but the fire was not large enough to be considered a saturated UV source to the detector. The minimum radiation required for detection is a function of the detectors sensitivity and varies between detectors. Detector manufactures use a type of saturated source to determine the detection speed of their detectors. These times are reported in manufacturer literature as follows:

Dual Spectrum	6 ms
Fire Sentry	$\geq$ 3.9 ms
Spectrex	$\leq$ 5 ms

1. Response of the detectors varies with the rate of flame growth of each material. The baseline Detector Electronics (Det Tronics) UV detector will respond as fast or faster than the three multi-spectrum detectors for the slow propagating materials (flame vertical growth <0.3 inches/millisecond) and it will respond slower for the faster propagating materials (> 1 in./ms, i.e. Red Lead and M206). The Fire Sentry and Dual Spectrum detector will respond similar and consistently fast for most materials. The Spectrex detector will perform slower than all other detectors for the slow propagating materials but equal to or faster than the Fire Sentry and Dual Spectrum detectors for fast propagating materials. Average response times for each detector and each material are shown in Table 1.

Table 1: Detector Response Time(ms) From the Detectable Event

	Fast Fire Propagation ⟷ Slow Fire Propagation						
	M206	**Red Lead**	**MK25**	**M125 Illuminate**	**Green Smoke**	**Yellow Smoke**	**First Fire**
Dual Spectrum	7	17	31 (1)	30 (2)	60 (3)	57	91 (4)
Fire Sentry	6	12	28	40 (3)	48	67	64 (1)
Spectrex	5	19	44 (6)	56 (7)	80 (4)	83 (2)	97 (5)
Det Tronics	11	21 (1)*	27 (1)	20	53	59	31

* - Number of events missed are listed in parenthesis.

Events missed listed in Table 1 are not to be interpreted as a detector failing to alarm to a flame. All detectors responded to the size and duration flames that was expected in Phase I testing. A missed event is explained as follows. During each test in Phase I, after 20 Feb 96, all detector response times were measured for each test, however, the detector connected to the control panel that activated the suppression system was changed from test to test. In some tests, when a faster responding detector was connected to the control panel, the fire was extinguished before a slower responding detector had time to alarm, thus causing a missed event for the slower detector. If the fire had not been extinguished as expediently, the slower responding detector would have detected the event. The missed event is entirely a test phenomenon and would not happen in a field application.

2. With the exception of the UV detector, each of the remaining three (3) detectors will perform exceptionally well against false alarm sources (see Appendix 2). The objective was to reduce false alarms by 95%. While this number is hard to quantify, the Spectrex detector, Dual Spectrum detector, and Fire Sentry detector will false alarm to less sources than the currently installed UV detector as seen in Table 2. Also, the UV detector will false alarm at the same distance as or most often at a much greater distance than the other detectors.

Table 2: Maximum Detector False Alarm Distance to a False Alarm Source

SOURCE	Minimum Distance Tested	Dual Spectrum	Fire Sentry	Spectrex	Detector Electronics
Butane Lighter	0.5 ft	**0.5 ft**	**1 ft**	**< 0.5 ft**	**16 ft**
Floodlight (650W)	2 ft	DN*	**2 ft**	DN	**2 ft**
Incandescent 75W light	0.083 ft	**0.5 ft**	DN	DN	**0.5 ft**
Philips EarthLight	0.083 ft	**0.083 ft**	DN	DN	DN
Floodlight (75W)	0.083 ft	**0.083 ft**	DN	DN	DN
3/8", 120VAC Drill	0.083 ft	DN	DN	DN	**15 ft**
1-inch Electric Arc	0.083 ft	DN	DN	DN	**16 ft**
Arc Welding	3 ft	**3 ft**	**6 ft**	DN	**24 ft**
Acetylene Torch	3 ft	**3 ft**	**12 ft**	**3 ft**	**12 ft**
Grinding mild steel	3 ft	DN	**3 ft**	DN	DN

* - Did Not alarm

3. The decision to buy a high-speed flame detector for installation is sight specific. A detector should be chosen based on local false alarm threats (see Table 2), fire growth rate of material to be suppressed, and on events that could lead to material ignition. If the anticipated threat is a fast growing fire (i.e. M206), the Spectrex detector will respond the fastest. If the threat is a slower growing fire, the Fire Sentry or Dual Spectrum detector should be used. If a slow growing flame is expected to ignite a fast growing material (like M206), then the detector that reacts to the slow growing flame the fastest should be installed.

4. The installation decision for a sphere water delivery system also depends on the specific sight. The 10L sphere completely discharges its water in 450ms. The 30L sphere discharges its water in 850 ms. Phase I testing was conducted with a 10L sphere along with the follow-on solenoid water valves. Additional testing with a 30L sphere will be conducted in Phase II.

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SECTION I

INTRODUCTION

A. OBJECTIVE

The objective of this program was to develop and demonstrate an advanced ultra high speed fire protection deluge system that will provide a 95% reduction in false alarms caused by ultraviolet (UV) emissions, provide a 75% reduction in response time compared to current systems installed at Army ordnance facilities and will extinguish each of the pyrotechnic materials tested. This false alarm objective is difficult to measure because of the lack of data available on actual numbers of false alarms experienced at plants and arsenals and the fact that some activations may not have been directly attributed to a false alarm source, but were documented as such. The bottom line, however, is to develop and or evaluate an optical detector(s) driven system that can "see" the various burns and is virtually immune to such false alarm sources as welding, various lights, lightning, motors, and similar stimuli. Detectors that are not only very fast, but also immune to false alarm sources, have been used in military applications with Halon 1301 systems in tanks and other armored vehicles. They have performed very well in evaluations as part of this Phase I effort. The most promising of these detectors will be "fine tuned" as necessary with spectral irradiance data obtained from spectral analysis performed as part of the Phase II work.

The goal for fire suppression was a 75% reduction in response time. The current standard for ultra high speed water suppression systems is NFPA 15 which requires 100 millisecond (ms) response time "for system operation from the presentation of an energy source to the detector to flow of water from the water spray nozzle being tested."[1] The energy source mentioned is not defined in the standard however for this discussion it is considered to be equivalent to a saturated ultraviolet energy source. Response time is a combination of several events including when the deflagration starts, the fire detector alarms, the control panel recognizes the alarm and activates the water deluge valves, and the suppression agent discharges. Gagnon[2] lists eleven time segments included in the response time which are discussed, as they relate to these tests, in Appendix 1.

An additional objective of this project was the optimization of existing systems through upgrades, modifications, technical enhancements, and operational procedures. A handbook depicting improvements that can be made in existing systems along with installation of a complete advanced fire protection deluge system will be provided to the Army as part of this project in Phase II of the effort.

B. BACKGROUND

Energetic materials which burn or deflagrate pose a significant risk to munitions production, maintenance, and renovation operations, as reflected by loses suffered by the U.S. Army Armament Munitions and Chemical command (now Industrial Operations Command) between 1988 and 1992. These costs totaled $9,500,000 and involved three deaths, nine serious

injuries, and severe property damage. Contractors, working with similar materials, under contract to the Department of Defense suffered an additional four deaths and severe property damage since 1991. Non-quantifiable costs included legal, environmental, investigative, lost production and mandated improvement requirements.

In various ordnance facilities fire detection and suppression systems have not fully kept up with advancements in new technologies. Many existing systems were improperly designed and installed. Such problems have been identified and documented by accident investigation teams, surveys, staff assistance visits, and project reviews. False alarms and system activations have occurred with serious impact on ordnance operations and on confidence in current detection and suppression systems. Response times of existing detectors are not consistent and may vary over a large range. The definition of deluge system response time is incomplete and not agreed upon. Further complicating the existing situation is the lack of standardized guidance and performance standards and the loss of personnel qualified to design, install, and maintain ultra high speed deluge systems.

In mid 1992, the U.S. Army Defense Ammunition Logistics Activity, formerly Program Manager for Ammunition Logistics (PM-AMMOLOG), at the suggestion of the U.S. Army Industrial Operations Command approached the Wright Laboratory Fire Research Section at Tyndall Air Force Base, Florida, to examine a joint approach to solving speed, effectiveness and false alarm problems with high speed deluge fire protection systems. It was believed that Army deluge experience coupled with Air Force fire protection knowledge would result in a viable solution to the problems with detection and false alarm activations. The U.S. Army proposed to have Wright Laboratory conduct a short study of the problems previously mentioned and to make recommendations for improvements. This study was conducted and a report published in September 1993[3]. Key items outlined in the report are as follows:

"A review of past test results substantiated the need for faster and more reliable fire detection and suppression approaches. Currently installed systems are, in general, not satisfactory for most types of pyrotechnic fire events. They lack the necessary speed, effectiveness and reliability. False alarms and accidental releases of fire suppressant continue to occur, although records of their occurrences are either sparse, or do not adequately describe their causes."

It was concluded from the study that there has been a lack of investment in R&D related to the problems of pyrotechnic fire detection, fire suppression, system performance and overall system reliability, and the study concluded with the following recommendations:

1. That various types of fire detection and suppression systems should be field-tested to determine the optimum configuration for each major application.

2. Attention should be given to testing the multi-spectrum IR detectors now in use for Army fighting vehicle crew compartment fire protection applications, and in the development of a fast response Machine Vision Fire Detector, being developed for slower response applications in the Air Force.

3. New technologies associated with rapid release of fire suppressant, being developed for Air Force aircraft use, may have excellent potential for this pyrotechnic fire application. One new area of technology that offers considerable promise to the fire suppression and extinguishing industry is the solid propellant technology that is being applied for inflation of automobile air bags. These nitrogen producing gas generators can expel finely atomized water stored in a pressure vessel located in close proximity to the potential fire location. A small high pressure vessel, pressurized around 2500 psi, could expel suppressant moving at very high velocity in about 10 ms.

Based on the report and continued interchange between the U.S. Army and the U.S. Air Force Wright Laboratory Airbase Technology Branch, a proposal was prepared to develop a program to build and test an advanced fire protection deluge system. The project concept and approach was briefed to the U.S. Army Defense Ammunition Logistics Activity in November 1994 and funding was provided in January 1995.

C. APPROACH

A prototype system was built and initial testing of the system started on 29 January 1996, with eight pyrotechnic materials provided from assembly line components found at U.S. Army plants and arsenals. The principle technical risk associated with this effort was providing reliability and safety in the fire detection/suppression system without sacrificing speed.

In this project, the research effort expanded on previous work to include the development of false alarm stimuli data. False alarm sources have caused significant problems with unplanned activations of existing optical fire detectors, primarily UV. Validation and testing of new technology IR, UV/IR, IR/IR, and visible detectors will eliminate many of these problems. False alarm stimuli tests were outlined in the test plan and conducted to assure that only the best performing "new" detectors are chosen for the prototype optimized system. The research effort also includes validating the detectability of pyrotechnic and propellant material flash fires; designing, operationally testing, and validating a prototype system, and, introducing new and superior technologies which enhance the capability of the current system to react faster to burning energetic materials. The feasibility of applying the new technologies developed by this project to tanks, armored personnel carriers, armored resupply vehicles, and other armored vehicles will be examined, subsequently by the Army.

One of the main goals of this undertaking was to take advantage of the ideas and improvements that have been made by innovative plant technicians over the years. One suggestion made during a field trip was to locate the water and detectors as close to the source of the burning hazard as possible, taking into consideration cost and safety. Detectors, sphere and follow-on water were all placed over a test table at a minimum height of 36 inches as shown in Figure 1. This would simulate a typical work station. The sphere was placed on an adjustable rack to make readjustments (up and down), as required to compensate for differences in propagation and burn rates of different materials. While a static position was maintained during

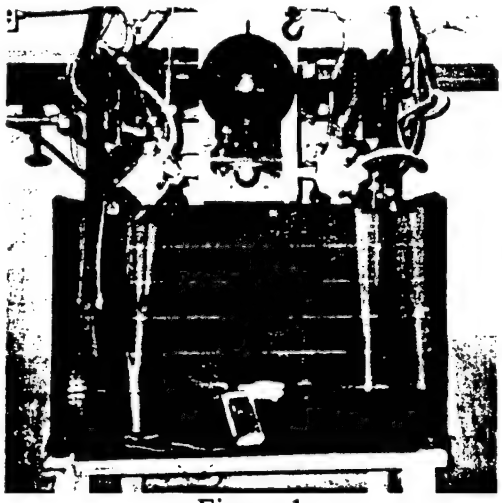


Figure 1
Detectors, 10L Sphere and Follow-on Nozzles at 36 inches

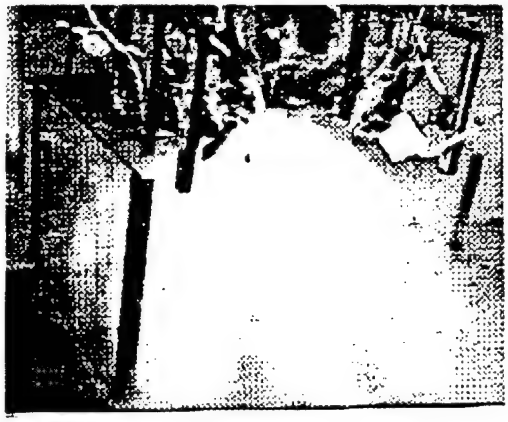


Figure 2
10L Sphere and Follow-on Water Discharge

most of the system testing at Tyndall AFB, varying adjustments will be required at the plants and arsenals where a variety of pyrotechnics are found.

Discharge Spheres

High rate discharge spheres were selected because it was believed that they could be successfully coupled with fast acting detectors and deliver agent quickly and effectively to a burning hazard, since the location of the hazard was known. Water was chosen as the agent of suppression because it provides a cooling effect that prevents feedback of sufficient heat energy to maintain combustion. It is desirable to get the water to the actual burning surface; however, this is not enough, as the fire will burrow into the mixture and continue to burn, being shielded from the water by an outer layer of water soaked material. This makes it essential to apply the water rapidly before burrowing can occur.

Another factor which makes rapid application essential is that water must reach the burning surface before the pressure of combustion gases is high enough to prevent it from reaching the source of the fire. This requires that the system operate in a matter of milliseconds.

Two sizes of spheres were tested (10 liters and 30 liters). These spheres were selected because they can be pressurized with nitrogen to about 750 psi of static pressure before a component rupture disc starts to leak. An initial setting of 500 psi of nitrogen was selected experimentally and has been ideal throughout the evaluations conducted on the table. The spheres are discharged via an internal squib (actuator) activated by a signal from the detectors through a control panel. Because the exploding actuator produces an internal pressure within the sphere, the nitrogen is further pressurized and creates a spring effect discharging the water at about twice the static pressure. Thus, when a sphere is pressurized to 500 psi, the water is expelled at about 1000 psi of pressure. A screen and spreader (see Figure 4) break the water into small atomized particles and assures even distribution and collection of the residual fragments of the squib.

A follow-on water system consisting of dual nozzle pressurized water provides additional cooling and extinguishment of the burning pyrotechnic or propellant hazard. This system is similar to current high-speed deluge systems installed in munitions plants. The system was pressurized to 150 psi during testing. In all tests conducted to date however, the 10 liter sphere has successfully controlled and extinguished the burn without the follow-on water.

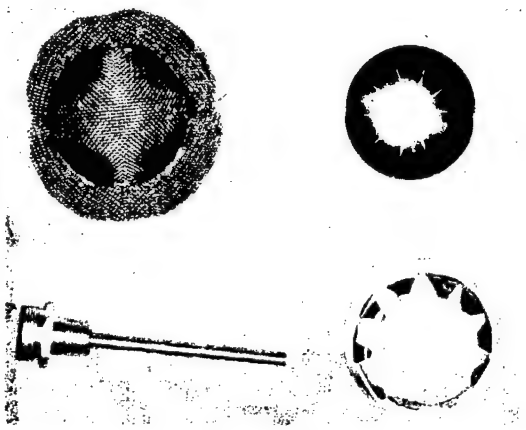


Figure 3
Clockwise from upper left: screen, rupture disk,
used rupture disk and exploding actuator

Detectors

Three dual band optical fire detectors were tested based on their advertised characteristics as being false alarm immune and able to detect burning pyrotechnic material in less than 5 milliseconds. These units were: Spectrex 620002 (SAFE) - UV/IR, Fire Sentry (SS2-AM & SS2 AML) - UV/IR, and the Dual Spectrum Santa Barbara PM-5SX IR/IR. These detectors are shown along with the Detector Electronics UV detector in Figure 4. Detector Electronics UV

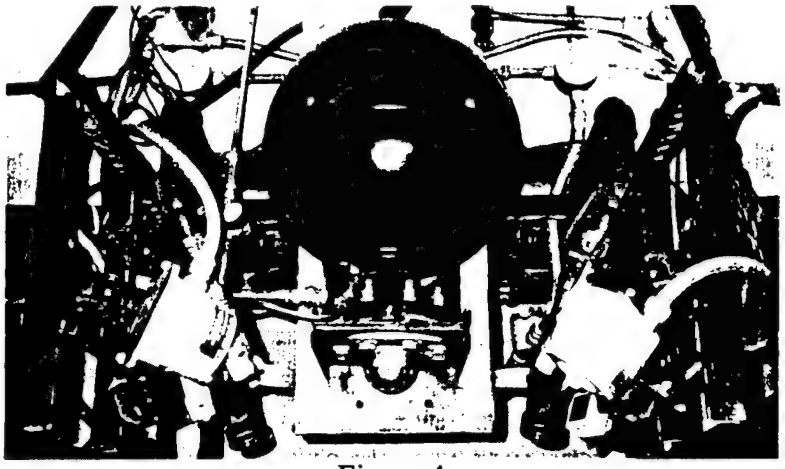


Figure 4
High Speed Detectors, 10L Sphere with spreader nozzle
located on bottom, and Follow-on water nozzles

optical fire detectors were used as a baseline. Most of the detectors presently used at Army plants with ultra high speed deluge systems are Detector Electronics UV units.

Although advertised as possessing false alarm resistance and ultra high speed characteristics, the dual band detectors had not been tested against burning energetic pyrotechnics and propellants as such materials are not available to private companies and the general public.

SECTION II

TEST PROTOCOL

A. GENERAL OBJECTIVE AND APPROACH

The general objective of this project was to "flesh out" a concept developed by the fire research engineers at Tyndall AFB FL that provides significant improvement in deluge system response times to pyrotechnic and propellant fire at plants and arsenals. The Sept 1993 report[3] "Evaluation of state-of-the-art High Speed Deluge Systems" presently in service at various U.S. Army Ammunition Plants provided valuable information and suggestions that required evaluation. Some of these suggestions included providing improved detection capability through use of new optical detectors, use of water as a cooling/extinguishment agent, and examining the use of solid propellant technology currently used in automobile air bags. The report also recommended evaluating machine vision technology - a system operating in the visible by retrieving stored video imagery of fire patterns and comparing this imagery to a new fire event. However, upon examination, machine vision was too slow at the time for an effective advanced fire protection deluge system.

Before completing design of an initial system prototype, Wright Laboratory Fire Research engineers visited various U.S. Army plants and arsenals obtaining useful information and concepts put into service at the locations. They also started development of a static high rate water discharge system using an external blasting cap, but altered this concept to utilize more efficient and safer units. The Army had voiced concern about the use of an external blasting cap that could inadvertently create sympathetic explosions or activate surrounding deluge systems.

After several months of work and evaluation the engineers renovated an existing facility (Figure 5) to accommodate munitions material deflagrations and built a prototype advanced fire protection deluge system. The prototype deluge system was initially tested with gasoline soaked sand and gunpowder, but was not evaluated with actual munitions material until formal testing started in January 1996.

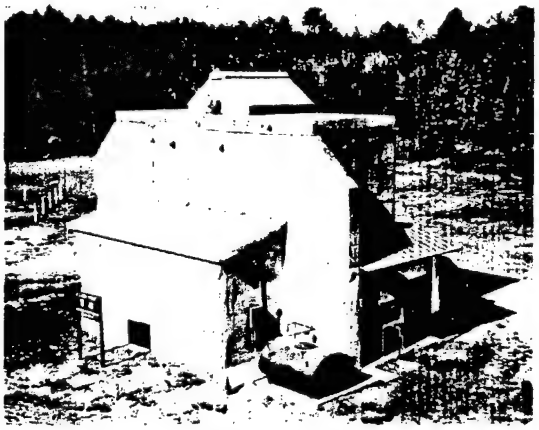


Figure 5
Advanced Fire Protection Deluge System Test Facility

A test plan was written concerning testing procedures and emergency actions and safety. Checklists were developed and refined in the initial stages of testing. Several pieces of equipment were borrowed from the Army including a high speed camera from McAlester Army Ammunition Plant (AAP), and UV detectors, electronic controllers, nozzles, various valves and fittings from Lone Star AAP. The Army, Pyrotech International, and the Department of Energy, Pantex Plant, also provided technical advice and helped refine the system prior to testing. A RAM/LAM electronic controller system was provided by Pyrotech International.

B. PYROTECHNIC MATERIAL TESTED

The following pyrotechnic material was "burned" in the testing and evaluation of the Advanced Fire Protection Deluge System during Phase I of the project. Material was provided by Longhorn Army Ammunition Plant (Texas), Crane Army Ammunition Activity (Indiana) and Pine Bluff Arsenal (Arkansas). Twenty pounds of each sample was transported to Tyndall using a military cargo plane:

* (1) **Illuminating Composition for MK 18 Project Load** Illuminating for MK 91 5"/54 Projectile, Illuminating Composition: Atomized Metal Powder (magnesium) (60%), Sodium Nitrate (35%), and binder (5%). HCSDS 41194. Hazard Classification: **Class 1.1G**

(2) **Starter Composition** Cupric oxide (30%), Lead Dioxide (80%), and Powdered Silicon (50%) for MK 25 Marine Locate Marker. HCSDS 40180. Hazard Classification: **Class 1.3G**

(3) **Delay Composition, Red Lead** Lead Oxide Tetra Red (80%), Silicon (16%), and Copolymer (4%) MK875 Flare Simulator. HCSDS 41192. Hazard Classification: **Class 1.3G**

(4) **Smoke Composition, Yellow** Dye - Solvent Yellow 33 (42%), Magnesium Carbonate (21%), Potassium Chlorate (22%), and sugar (15%) for M18 Hand Grenade, Smoke Yellow. HCSDS 20056. Hazard Classification: **Class 1.3G**

(5) **Smoke Composition, Green** Dye - Solvent Yellow 33 (12.5), Dye - Solvent Green 3 (29.5%), Magnesium Carbonate (17%), Potassium Chlorate (24.5%), and sugar (16.5%) for M18 Hand Grenade, Smoke Green. HCSDS 20055. Hazard Classification: **Class 1.3G**

(6) **M206 IR Flare Composition** Magnesium, Polytetrafluorethylene (TFE-Fluorocarbon), Hycar Dry Rubber, and Acetone and/or Magnesium (62-75%). Fluorollostomer (5-18%), and TFE (7-43%) for M206 IR Counter Measures Flare. HCSDS 1106 and 1107. Hazard Classification: **Class 1.3G**

(7) **First Fire Mixture (Type I)** Barium Nitrate (50%), Tetranitrocarbazole (10%), Zirconim Hydride (15%), Silicon (20%), Resin (2%). HCSDS 40129. Hazard Classification: **Class 1.3G**

(8) **M125 Illuminate Composition** Magnesium Type IV 30/50 (33%), Barium Nitrate/Class 6 (46%), Polyvinyl Chloride (16%), and Laminac (9%) for the M125 Signal, Illumination, Ground Star Cluster. HCSDS 1478. Hazard Classification: **Class 1.1D**

* Shortly after testing began this material became too hard to break up into small samples. No further testing was done on the material and the remaining samples were destroyed.

C. TEST PROCEDURES

The prototype system was tested with 1/4 to 1/2 lb samples of eight different pyrotechnic compositions. They ranged from benign to very energetic compositions including smoke, first fire, illumination mixes and IR decoy flare mix. Each material was tested with each of the four detectors. The Detector Electronics UV detector is used widely in Army ammunition plants and was used as a baseline for comparisons. Each test was repeated three times to ensure the results were statistically valid. Each sample was placed in a small pile (in metal pan) on the center of the 4'X4' table. An electric match with smokeless gunpowder was used as an ignition source for the "burn". These matches were placed on the bottom of the pile. All tests with the 1/4 to 1/2 lb samples on the test table were conducted with the 10 liter sphere with 22 lbs of water (about 3 gallons) nitrogen pressurized to 500 psi. Approximately 100 total evaluations were accomplished in Phase I on the table.

The three dual band optical detectors and the Detector Electronics UV unit were subjected to extensive false alarm stimuli testing. These stimuli included floodlights, flashlights, neon drop lights, sunlight, chopped light (flood light and drop light sources), drill motor (with sparks), and MIG and stick welding (mild steel, aluminum, stainless steel) with various currents and rods. Distances for welding operations included two, three, six, nine and twelve foot distances from the detectors. The UV detector was subjected to welding operations at distances beyond twelve feet including outside welding at over twenty four feet. Detector performance comparisons are included in Appendix 2.

D. TESTING RESULTS

All testing was accomplished in accordance with the test plan. The tests were conducted using trained explosive ordnance disposal (EOD) and laboratory technicians. Extensive checklists were developed and followed. The evaluations were recorded on standard speed video and on a high speed video (1000 frames per second) Kodak camera borrowed from the U.S. Army. Each test was written up separately and the events recorded in a log book. Data recorded for each event was depicted in milliseconds and included a detectable event to sphere discharge time (see Figure 6), detectable event to sphere water on hazard flame time, detectable event to sphere water on table time (see Figure 7), detectable event to follow-on water time and detectable event to fire suppression time. All of these data were directly measured from observations recorded on the high speed camera and a data recorder. Although each test was configured to evaluate a particular detector's ability to "see" an event and activate the suppression system, a measurement

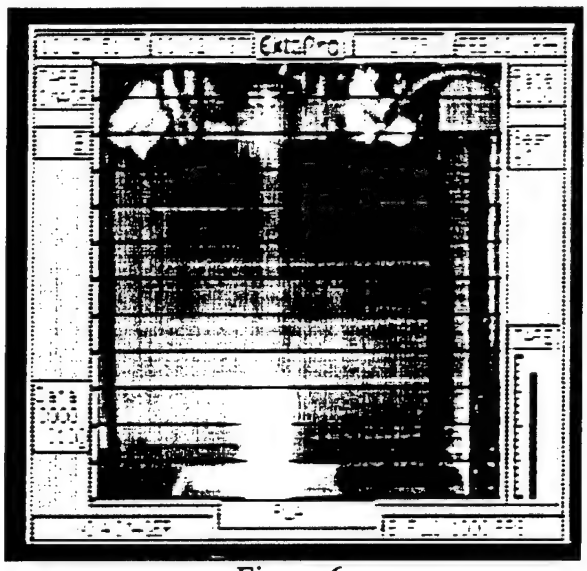


Figure 6
Sphere Discharge

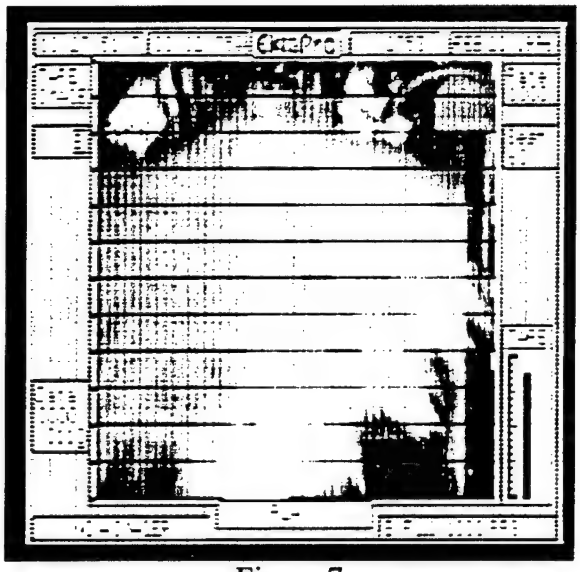


Figure 7
Sphere Water on Table

of how fast the other detectors reacted to that same event was also made. A summary of each test conducted is included in Appendix 3.

In every test conducted, the burning material was detected and extinguished by the advanced fire protection deluge system. In most cases considerable amounts of unburned residue remained on the table, on the lexan shield around the table and on the floor. This indicated that the system was catching and interrupting the burn before further propagation occurred. A few of the materials however, were water soluble (smokes for example) and dissolved in the residual water. It could not be determined if all of this material burned. Each material "burn" produced varying system response times, as seen in Table 1, with the energetic materials (red lead and M206 mix) producing the fastest response. The slower times usually occurred with the smoke mixes which partially obscured the detectors field of view. The smokes also required more time to "ramp-up" to an equivalent size fire of say M206 IR flare mix, for example. One M206 IR flare fire grew to a diameter of 31 inches in two milliseconds. The same fire from a smoke mix would require 300 milliseconds to grow to this size. A summary of graphic presentations for various burning pyrotechnic characteristics is included at Appendix 1.

The new detector and sphere deluge system responds to M206 in 8 ms on average (6 ms average detector response and 2 ms average sphere discharge response). The current standard for ultra high speed water suppression systems is NFPA 15 which requires 100 millisecond (ms) response time "for system operation from the presentation of an energy source to the detector to flow of water from the water spray nozzle being tested."[1] The energy source mentioned is not defined in the standard however for this discussion it is considered to be equivalent to a saturated ultraviolet energy source. This is best demonstrated in our tests by the M206 Flare Composition reaction. This material propagates when burning at an average rate of 10 inches per millisecond.

Testing found that currently installed control panel and deluge systems can respond in 36 ms after a fire detector activation when the air is properly bled from the supply lines. The control panel and sphere deluge system developed in this program respond in two milliseconds after a fire detector activation. Also, the water velocity is much greater for the new deluge system. After exiting the nozzle, water reaches the burning material 36 inches away in 18 ms compared to 90 ms for the existing system.

The sphere water provided enough cooling to quickly and effectively control and extinguish the burning munitions for the materials and quantities tested in this program. Although pressurized follow-on water was present in each deflagration test, it was not required to control and extinguish the burning pyrotechnic material.

E. CONCLUSIONS

The results from the Phase I development and testing of an advanced fire protection deluge system have clearly shown that this system has tremendous potential for selected applications in various government and commercial munitions manufacturing or handling activities. Several key questions have been answered that were unknowns prior to testing of the system. It is now known that deluge systems can be designed to react fast enough to save lives in cases where highly energetic pyrotechnic material such as red lead is used. It is now known that a very high degree of false alarm immunity can be achieved along with speed by using state of the art detectors designed for military applications in such weapons as tanks and armored personnel carriers. These detectors have successfully activated Halon 1301 systems for fuel explosions caused by penetrating projectiles in the Desert Storm Gulf War. The following are specific conclusions that have been drawn for this report based upon the testing done to date. Additional testing will be accomplished in Phase II of this project.

1. Response of the detectors varies with the rate of flame growth of each material. The baseline Detector Electronics (Det Tronics) UV detector will respond as fast or faster than the three multi-spectrum detectors for the slow propagating materials (flame vertical growth <0.3 inches/millisecond) and it will respond slower for the faster propagating materials (> 1 in./ms, i.e. Red Lead and M206). The Fire Sentry and Dual Spectrum detector will respond similar and consistently fast for most materials. The Spectrex detector will perform slower than all other detectors for the slow propagating materials but equal to or faster than the Fire Sentry and Dual Spectrum detectors for fast propagating materials. Average response times for each detector and each material are shown in Table 1.

Events missed listed in Table 1 are not to be interpreted as a detector failing to alarm to a flame. All detectors responded to the size and duration flames that was expected in Phase I testing. A missed event is explained as follows. During each test in Phase I, after 20 Feb 96, all detector response times were measured for each test, however, the detector connected to the control panel that activated the suppression system was changed from test to test. In some tests, when a faster responding detector was connected to the control panel, the fire was extinguished before a slower responding detector had time to alarm, thus causing a missed event for the

slower detector. If the fire had not been extinguished as expediently, the slower responding detector

Table 1: Detector Response Time(ms) From the Detectable Event

	Fast Fire Propagation ←---------→ Slow Fire Propagation						
	M206	**Red Lead**	**MK25**	**M125 Illuminate**	**Green Smoke**	**Yellow Smoke**	**First Fire**
Dual Spectrum	7	17	31 (1)	30 (2)	60 (3)	57	91 (4)
Fire Sentry	6	12	28	40 (3)	48	67	64 (1)
Spectrex	5	19	44 (6)	56 (7)	80 (4)	83 (2)	97 (5)
Det Tronics	11	21 (1)*	27 (1)	20	53	59	31

* - Number of events missed are listed in parenthesis.

would have detected the event. The missed event is entirely a test phenomenon and would not happen in a field application.

2. With the exception of the UV detector, each of the remaining three (3) detectors will perform exceptionally well against false alarm sources (see Appendix 2). The objective was to reduce false alarms by 95%. While this number is hard to quantify, the Spectrex detector, Dual Spectrum detector, and Fire Sentry detector will false alarm to less sources than the currently installed UV detector as seen in Table 2. Also, the UV detector will false alarm at the same distance as or most often at a much greater distance than the other detectors.

Table 2: Maximum Detector False Alarm Distance to a False Alarm Source

SOURCE	**Minimum Distance Tested**	**Dual Spectrum**	**Fire Sentry**	**Spectrex**	**Detector Electronics**
Butane Lighter	0.5 ft	**0.5 ft**	**1 ft**	**< 0.5 ft**	**16 ft**
Floodlight (650W)	2 ft	DN*	**2 ft**	DN	**2 ft**
Incandescent 75W light	0.083 ft	**0.5 ft**	DN	DN	**0.5 ft**
Philips EarthLight	0.083 ft	**0.083 ft**	DN	DN	DN
Floodlight (75W)	0.083 ft	**0.083 ft**	DN	DN	DN
3/8", 120VAC Drill	0.083 ft	DN	DN	DN	**15 ft**
1-inch Electric Arc	0.083 ft	DN	DN	DN	**16 ft**
Arc Welding	3 ft	**3 ft**	**6 ft**	DN	**24 ft**
Acetylene Torch	3 ft	**3 ft**	**12 ft**	**3 ft**	**12 ft**
Grinding mild steel	3 ft	DN	**3 ft**	DN	DN

• - Did Not alarm

3. The decision to buy a high-speed flame detector for installation is sight specific. A detector should be chosen based on local false alarm threats (see Table 2), fire growth rate of material to be suppressed, and on events that could lead to material ignition. If the anticipated threat is a fast growing fire (i.e. M206), the Spectrex detector will respond the fastest. If the threat is a slower growing fire, the Fire Sentry or Dual Spectrum detector should be used. If a

slow growing flame is expected to ignite a fast growing material (like M206), then the detector that reacts to the slow growing flame the fastest should be installed.

4. The installation decision for a sphere water delivery system also depends on the specific sight. The 10L sphere completely discharges its water in 450ms. The 30L sphere discharges its water in 850 ms. Phase I testing was conducted with a 10L sphere along with the follow-on solenoid water valves. Additional testing with a 30L sphere will be conducted in Phase II.

F. RECOMMENDATIONS

1. The currently installed pressurized water should remain as part of the system as a back up to the sphere to provide continued cooling and extinguishment as may be required. However, the sphere can be used as a stand alone unit when demonstrated to be effective. Further recommendations will be included in the final report for Phase II. The Phase II effort will also include the following:

a. Measuring spectral emissions from the burning materials and provide the data to the manufacturers for detector adjustments.
b. Evaluate manufacturer's changes based on spectral analysis data.
c. Testing several "new" pyrotechnics and propellants (listed below).
d. Evaluating the system for powder charging stations.
e. Developing an operations handbook and drawings.

The following materials will be tested as part of Phase II. Spectral analysis work will include these and the materials tested in Phase I.

(1) **Incendiary Composition, RS-40** Magnesium Aluminum Alloy (49.5%), Ammonium Nitrate (24%), Aerocell (0.5%), Barium Nitrate (24%), and Calcium Resinate Fuzed (2%). Hazard Classification: **Class 1.1G**

(2) **Incendiary Composition, RS-41** Magnesium Aluminum Alloy (48%), Calcium Resinate Fuzed (2%) and Potassium Perchlorate (50%). Hazard Classification: **Class 1.1G**

(3) **Dim Tracer Composition, R-440** Barium Peroxide (41.5%), Strontium Peroxide (41.5%), Calcium Resinate Fuzed (10%) and Magnesium Carbonate (8%). HCSDS 1608. Hazard Classification: **Class 1.1G**

(4) **Propellant, Hy-Skor 700X** Nitrocellulose and Nitroglycerin. HCSDS 1628. Hazard Classification: **Class 1.1C**

(5) **Propellant, M14** Nitrocellulose (90%), Dinitrothene (8%), Dibutylphalate (2%), and Diphenylamine (1%). HCSDS 1912. Hazard Classification: **Class 1.3C**

(6) **Propellant, JA-2** Nitrocellulose (59.5%), Diethylene Glycol Dinitrate (24.8%), Nitroglycerin (14.9%), Magnesium Oxide (0.04-0.05%), N-Methyl-N'-N'Diphenylurea (0.7%), and Graphite (0.24-0.25%). HCSDS 1258. Hazard Classification: **Class 1.3C**

(7) **Propellant, LKL** Nitrocellulose (93.6%), Dinitrotoluene (3%), Potassium Sulfate (1.4%), Dibutylphthalata (1%), Diphenylamine (1%) and Graphite (0.2%). HCSDS 1805. Hazard Classification: **Class 1.3C**

(8) **Explosive Molding Powder, LX-17-0** Chemical Name: 2,4,6-trinitro-1,3,5-benzenetriamine. Composition: TATB (92.5%) and Kel-F800 (7.5%). Hazard Classification: **Class 1.1D**

(9) **Explosive Molding Powder, PBX-9501** Composition: HMX (95%), Estane (2.5%), BIS (2, 2-Dinitropropyl)Acetal (BDNPA) (1.25%), and %), BIS (2, 2-Dinitropropyl)Formal(ADNPF) (1.25%). HCSDS 1006. Hazard Classification: **Class 1.1D**

(10) **Explosive Molding Powder, PBX-9502** Composition: TATB (95%) and Kel-F800 (5%). Hazard Classification: **Class 1.1D**

2. Problems with the "sputtering" response of the pressurized water nozzles should be evaluated. This problem is discussed in Appendix 1.

REFERENCES

1. NFPA 15. Water Spray Fixed Systems for Fire Protection. National Fire Codes. National Fire Protection Association, Inc. Quincy, MA. 1996.

2. Gagnon, Robert N. Ultra High Speed Suppression Systems for Explosive Hazards. Fire Protection Handbook, Eighteenth Edition, National Fire Protection Association, 1997.

3. Goedeke, A.D., Fadorsen, G.A. Evaluation of State-of-the-Art High Speed Deluge Systems Presently in Service at Various U.S. Army Ammunition Plants. WL-TR-93-3510. September 1993.

BIBLIOGRAPHY

1. Loyd, Robert A., Evaluation of Ultra-High-Speed Fire Protection Systems Presently in Service at Army Ammunition Plants, U.S. Army Armament, Munitions and Chemical Command Safety Office, Department of Defense Explosives Safety Seminar, August 1994.

2. Kennedy, P.E., O'Brian, G.P., Patel, S.H. Study to Investigate Portable Ultra High Speed Deluge Systems, U.S. Army Production Base Modernization Activity, Contract # DAAA21-86-D-0033, August 1988.

3. McIntyre, F.L., Rindner, R.M., A Compilation of Hazard Test Data for Pyrotechnic Compositions, Report # ARLCD-CR-80047, ARRADCOM, TSD. March 1979.

4. Military Handbook, MIL-HDBK-1008B, Fire Protection for Facilities Engineering, Design, and Construction, March 1988.

5. Vargas, Luis M., Garza, Luis R., Caltagirone, Joseph P., Pyrotechnic Fire Suppression System Evaluation, U.S. Army Armament Research, Development and Engineering Center.

APPENDIX 1

SUPPRESSION SYSTEM TEST DATA

This appendix reports on the data gathered during the first series of testing of the advanced fire protection deluge system. During this series of tests eight different pyrotechnic materials were ignited under similar conditions in order to measure the suppression efficiency of the system. Four sets of detectors observed the event with one unit set to activate the suppression system and the other detector activation times recorded for comparison. The selected detectors were:

A. Det Tronics R7303, C7050B Combination UV Fire Detection System (UV)

B. Dual Spectrum PM-5SX Fire Sensor (IR/IR)

C. Spectrex SN 620002 (UV/IR)

D. Fire Sentry SS2-A Multi-Spectrum Fire Detector (UV/IR)

When the selected detector alarms a signal is sent to two separate water suppression systems. The primary is the high rate discharge extinguisher (sphere) and the secondary system is the industry standard, pressurized nozzles.

The whole series of fire tests involved several possible variables that were held constant based on empirical procedures. The sphere size selected was 10L and pressurized to 500 psi. The follow-on water was pressurized to 150 psi. A small sample of pyrotechnic material was placed on a table with three sides enclosed, to simulate a typical industry workstation. All detectors, the sphere, and the nozzles were located 36 inches above the table. All detector signals were processed through a Pyrotech International RAM/LAM controller which operated in less than one millisecond. The RAM/LAM controller provides a quick capacitive discharge to both the detonator in the sphere and the 24 VDC solenoid, pilot valve for the follow-on water.

High speed deluge tests include several events where data collection is necessary for evaluation. Gagnon[2] listed 11 time segments that occur during a test and how they relate to NFPA 15[1] and system evaluations. Following is a list of the time segments during these Phase I tests which vary slightly from Gagnon:

1. Event Initiation - The button is pushed to ignite the electric match and start the test.
2. Deflagration begins.
3. Detectable Event - The first indication of a visible fire ball (deflagration) generated by the ignited material as viewed on the high speed camera that should be "seen" by a detector.
4. The flame grows to a size where the radiation released is sufficient for detector reaction.

5. Detector Alarm - The fire detector sends a fire alarm signal to the control panel. The radiation required for detection varies with each detector's sensitivity and affects detection time.
6. Controller Out - The control panel, after receiving the signal from the flame detector, sends a signal to the water discharge devices.
7. The squib and solenoid valves receive the signal from the control panel and begin to react.
8. Water Discharge - Water exits the nozzle.
9. Water from the nozzle reaches the burning material.
10. Fire Suppression (extinguishment) - The first indication on the high speed camera of no fireball remaining.

Some of these time segments and system performance are depicted by two pages of high speed video still shots and a series of graphs attached to this appendix (Graphs 1 - 24). Detector Response Time is defined for these tests as that time between segments 3 and 5. Response of the detectors varies with the rate of flame growth of each material. Sphere Response Time and Nozzle Response Time are measured from segment 6 to segment 8. Sphere Response Time varied from 1-4 ms but typically was 2 ms. The control panel response time from segment 5 to 6 was measured to be less than 0.2 ms, almost instantaneous relative to Phase I testing.

The time from event initiation until the detectable event varies with each material (some materials require more heating). The average times from event initiation to detectable event for each material are shown in Table 3 (this data was measured on the high speed camera). This type of data has been included in previous high speed deluge test reports, however for the purpose of evaluating the Advanced High Speed Deluge System, the data before the detectable event was not relevant. All other test data is included in Graphs 1-24 and in Appendix 3.

Table 3: Average Interval from Event Initiation to Detectable Event

MATERIAL TESTED	TIME (MS)	MATERIAL TESTED	TIME (MS)
MK-18 Project Load	443	Green Smoke	1397
MK25 Starter Comp	572	M206	20
Red Lead	14	First Fire (type I)	98
Yellow Smoke	727	M125 Illuminate Comp.	532

Graph 1 displays the average responses for the two suppression methods (sphere and follow-on water). The data points for the sphere data were derived from 27 actual munitions tests excluding the fastest acting materials (red lead and M206 IR flare mix). These materials produced large bright fireballs that make clear definition of the sphere water on the high speed camera impossible to see (see page 27). The sphere data is very consistent and repeatable. If the detector "sees" the fire when it is small enough, there is a clear view of the release of sphere water on the high speed camera. In every test completed the sphere discharged first, followed by the follow-on water. In addition, the water left the sphere nozzle at a higher velocity allowing the water to reach the hazard faster. It is evident from the Graph 1 that the sphere performs a much better job of getting water to the fire in minimum time.

One of the eight materials tested was MK18 Project Load. The material hardened however and was deemed not testable after 12 Mar 96. For this reason only three tests were performed, leading to very limited data for this material. Graph 2 shows the average propagation rate of the ignited material's fireball. Graph 3 is a graphical representation of an actual test. The fire increases in size from the detectable event. The selected detector "sees" the fire and activates the suppression systems. Almost instantly the sphere water is hurled toward the still enlarging fire. When the sphere water reaches the fire, the fire is quickly extinguished. A short time later the follow-on water is on its way to the table to continue cooling.

The rest of the graphs in this appendix is divided into sets of three, one set for each material.

As portrayed on the following graphs, water obscuration presented minor problems in recovering data from the tests in detector responses and in fire propagation data. Water from the sphere was on the flame in at least 18 milliseconds after detection for all tests conducted at 36 inches. In some tests the water blocked the view of detectors which had not yet determined that a flame was present and these detectors did not alarm (Note: Beginning 20 February 1995, all detector response times were recorded for each test, however only one detector activated the suppression system). This is denoted as an "event missed" on the bar graphs. This happened more often with the materials that propagate slower.

Determining fire propagation data was also hindered by the water. Fire propagation rates were found by reviewing high-speed video data. The water from the sphere sometimes caused problems in determining flame size. Also, the intense light from the flame saturated the camera in some tests. Data could not be recovered under these conditions, and thus is estimated in the following graphs.

Follow-On Water Improvements

Due to a "sputtering" phenomenon with the follow-on water during deluge fire suppression tests, several tests were performed with only the follow-on water dual nozzles in order to observe their reaction. Upon activation of the nozzle, the flow quickly diminished to a trickle for 70-100 ms before coming out full force. This phenomenon would normally not be noticed without the use of a high speed camera. Still photos from the high speed video are shown in Figures 1-1 - 1-3. This problem may be limited only to the system tested at Tyndall AFB or it could be wide-spread in the field. In either case it warrants further investigation. The cause of this phenomenon has not been determined, however a solution has been found. At Tyndall AFB, a two gallon hydraulic accumulator installed close to the nozzles resulted in both elimination of sputter and a decrease in response time. Some possible causes of this are hydraulic flow through the piping or through the nozzle.

Phase I follow-on water response time varied between 53-106 ms from controller out until water exits the nozzle. After completion of the Phase I tests, an improvement was made in procedures for bleeding air from the water supply line and the response times observed were 30-

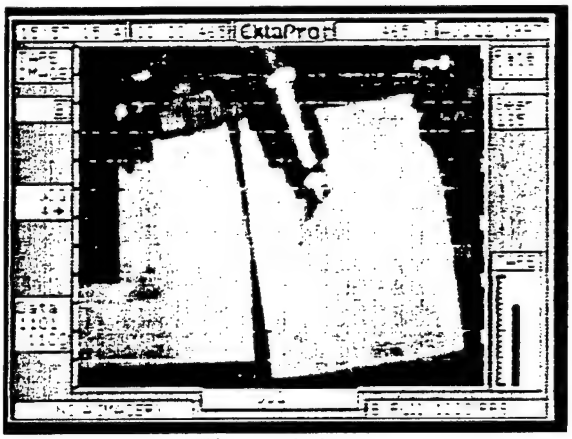


Figure 1-1
Nozzle Sputter shown 73 ms after
Controller Signal Output
w/o Accumulator

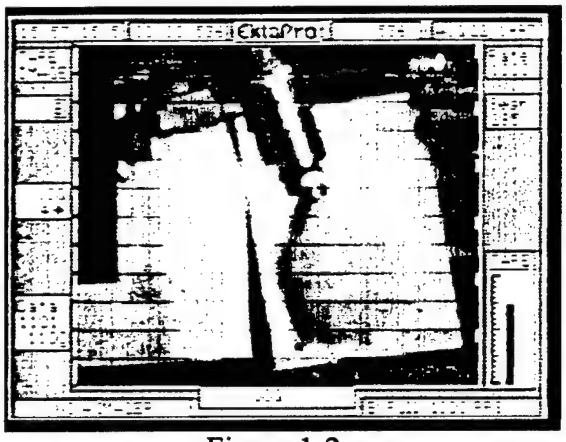


Figure 1-2
Nozzle Full Flow shown 144 ms after
Controller Signal Output
w/o Accumulator

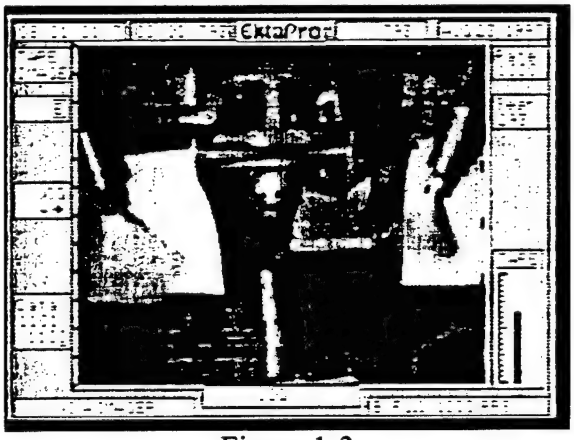


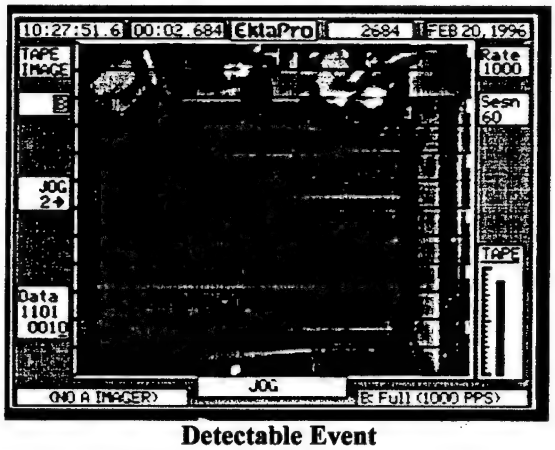
Figure 1-3
Nozzle Full Flow shown 40 ms after Controller Signal Output
With Accumulator

45 ms, however sputtering was still present (see Figures 1-1 and 1-2). After the addition of the accumulator, response times were consistently 27-31 ms with no sputtering (see Figure 1-3). The improvement in response time and flow rate is obvious in Graph 1. The original results, before the improvements, are shown in the remaining graphs.

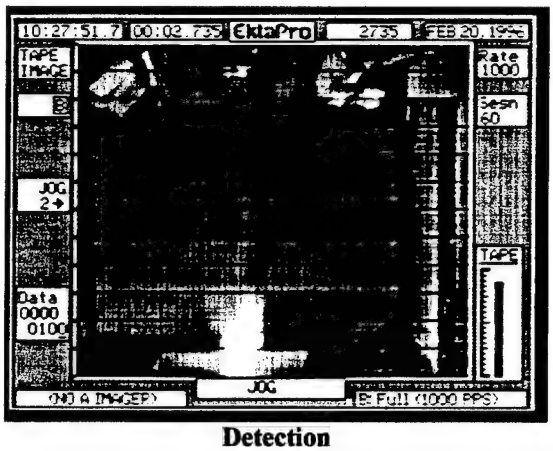
High Speed Video Data Collection

February 20, 1996 M125 Illuminate Composition

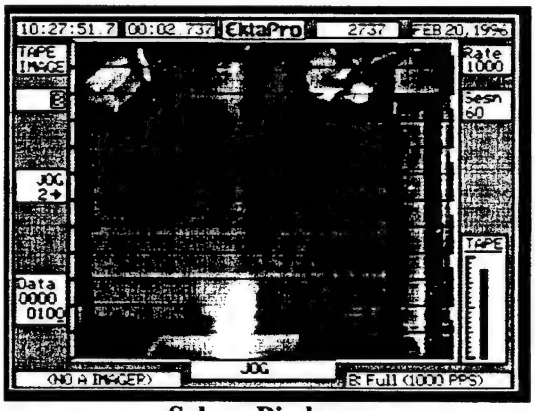
(Details of this test in Appendix III)



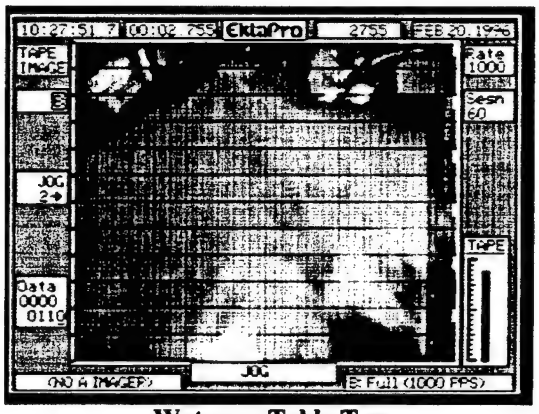
Detectable Event
(532 ms after match initiation)
(Time 0 on Charts)



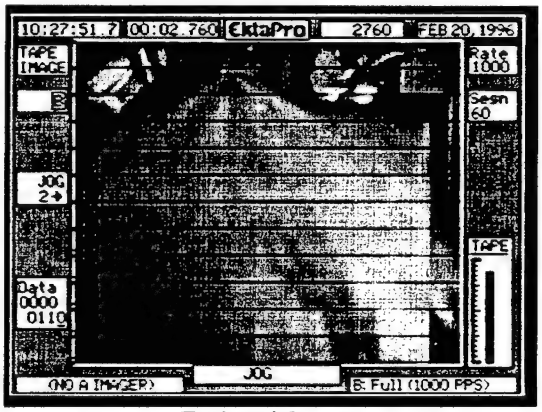
Detection
(58ms after Detectable Event)
(Flame 8 inches High)



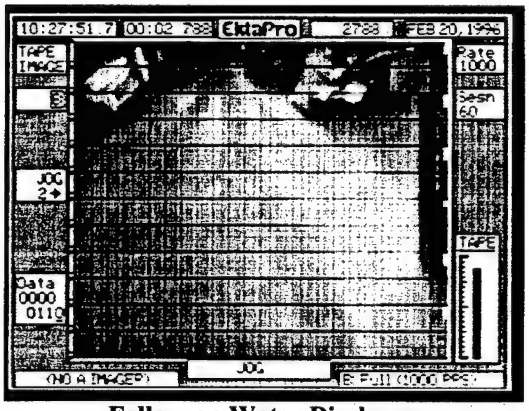
Sphere Discharge
(2 ms after Detection)
(Water 35 inches above Tabletop)



Water on Table Top
(18 ms after Detection)
(Water 0 inches above Tabletop)



Extinguishment
(23 ms after Detection)
(Fire at 0 inches)

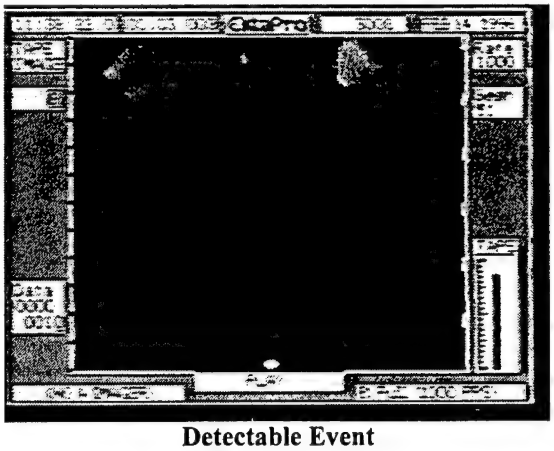


Follow-on Water Discharge
(41 ms after Detection)
(Follow-on Water at 35 inches above Tabletop)

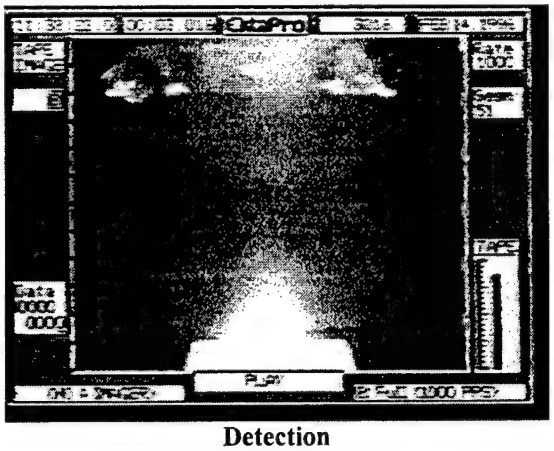
High Speed Video Data Collection

February 14, 1996 Red Lead

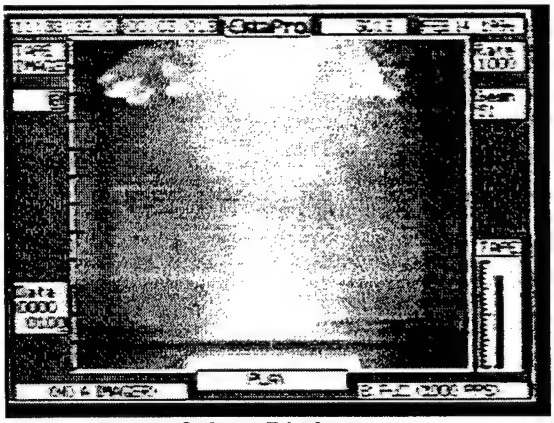
(Details of this test in Appendix III)



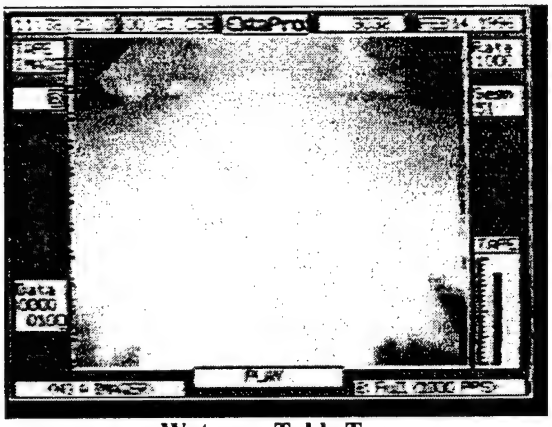
Detectable Event
(9 ms after match initiation)
(Time 0 on Charts)



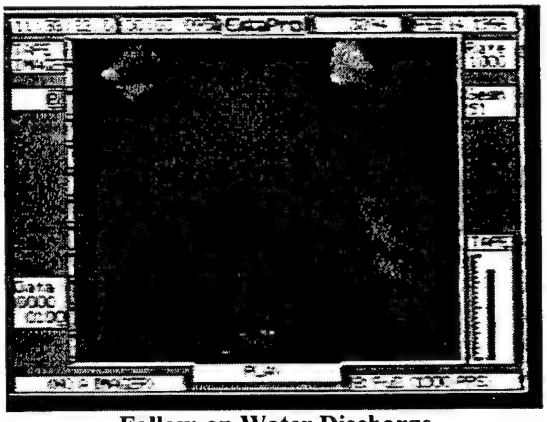
Detection
(9 ms after Detectable Event)
(Flame 11 inches High)



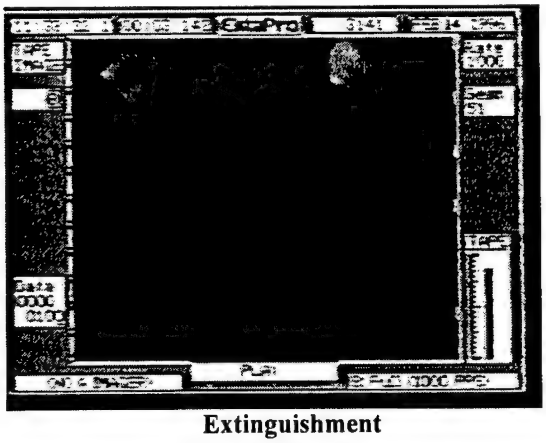
Sphere Discharge
(2 ms after Detection)
(Water 35 inches above Tabletop)



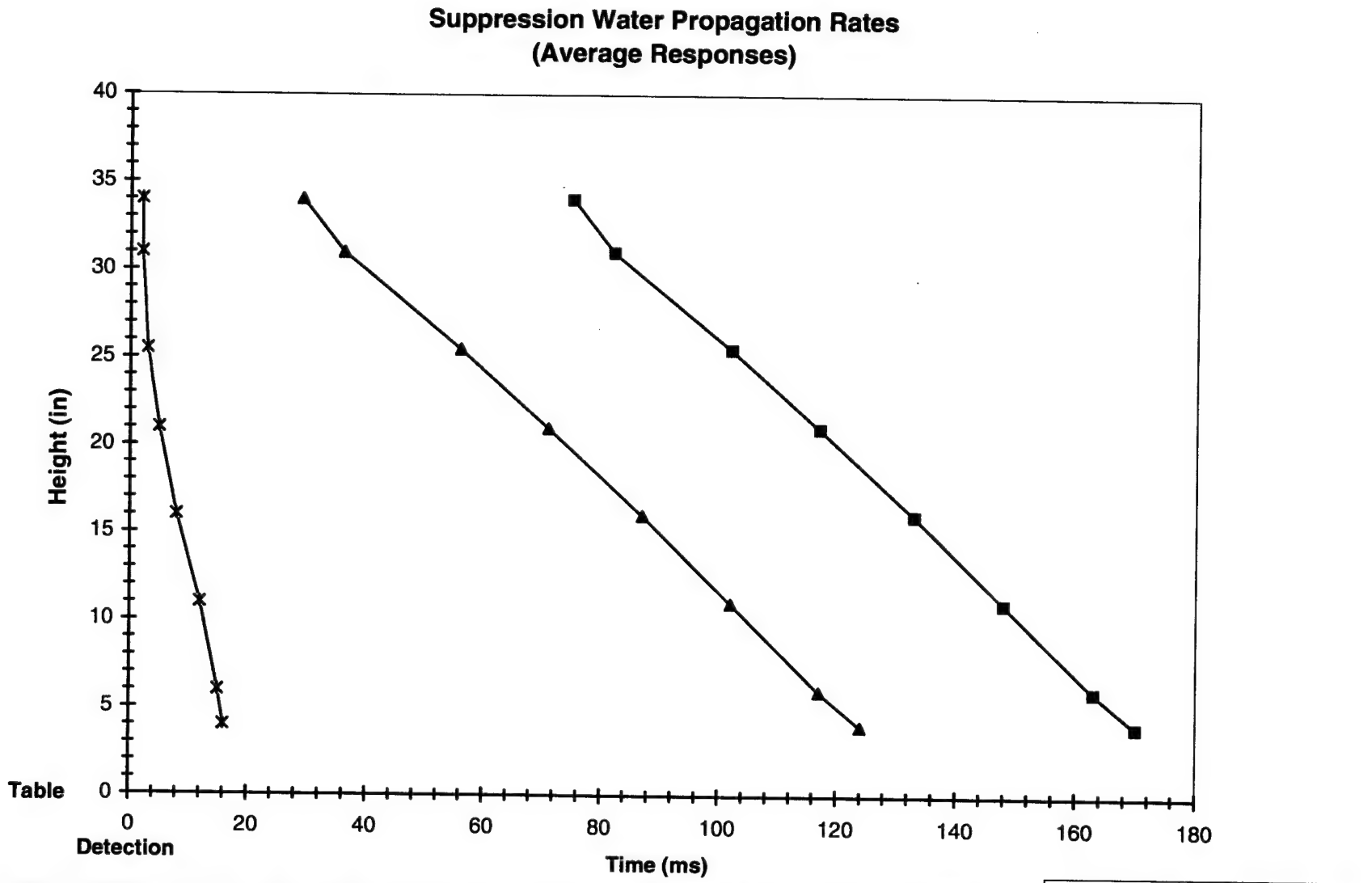
Water on Table Top
(22 ms after Detection)
(Water 0 inches above Tabletop)



Follow-on Water Discharge
(74 ms after Detection)
(Follow-on Water at 35 inches above Tabletop)



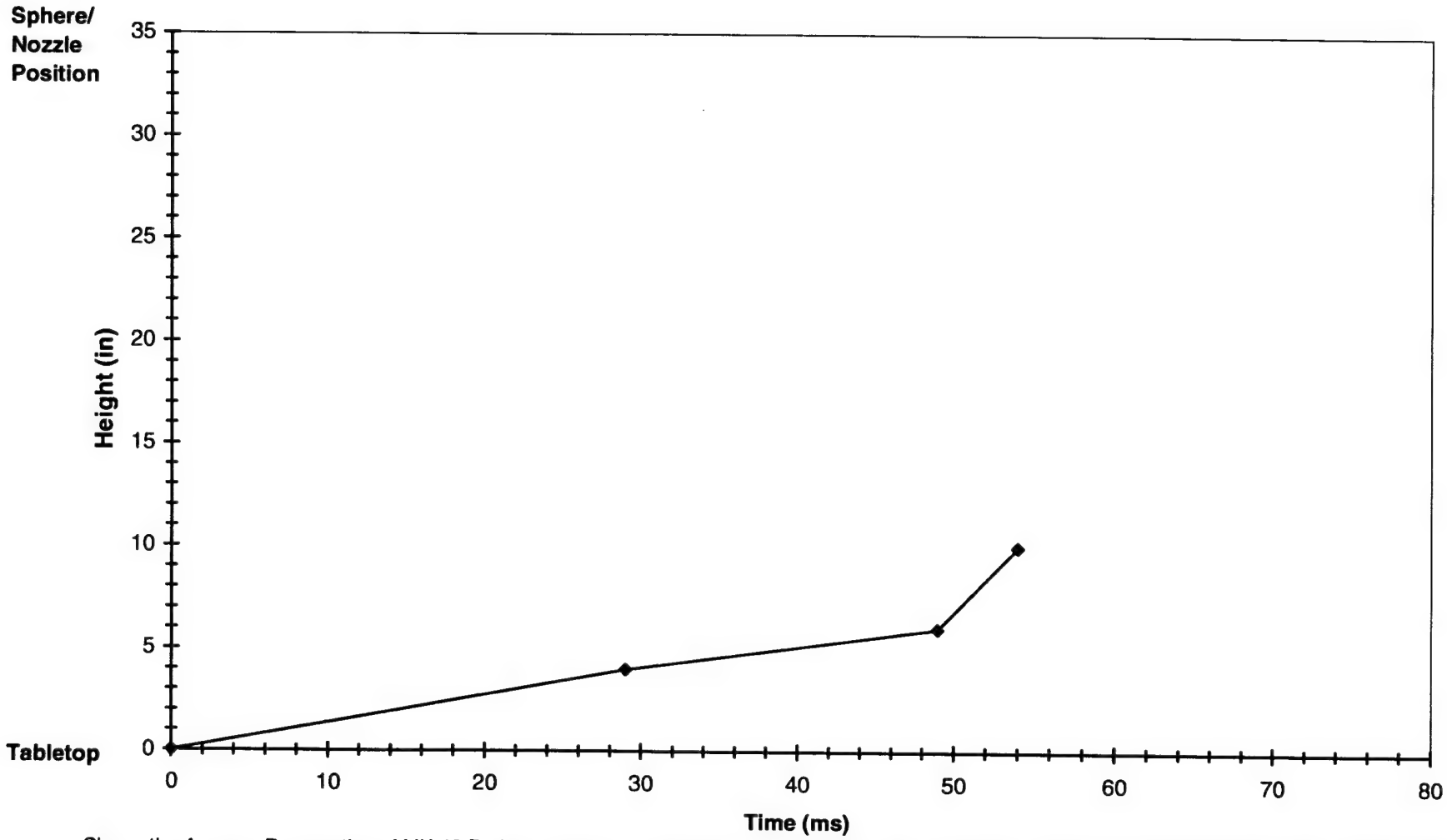
Extinguishment
(124 ms after Detection)
(Fire at 0 inches)



This graph compares the sphere water system response time to follow-on water response time. It shows the Average Propagation of water from the nozzle (at height 36 in.) to the tabletop (at 0 in.) from time of detection. The follow-on water system improvements were realized after completion of these tests, the following graphs show original results only.

Graph 1

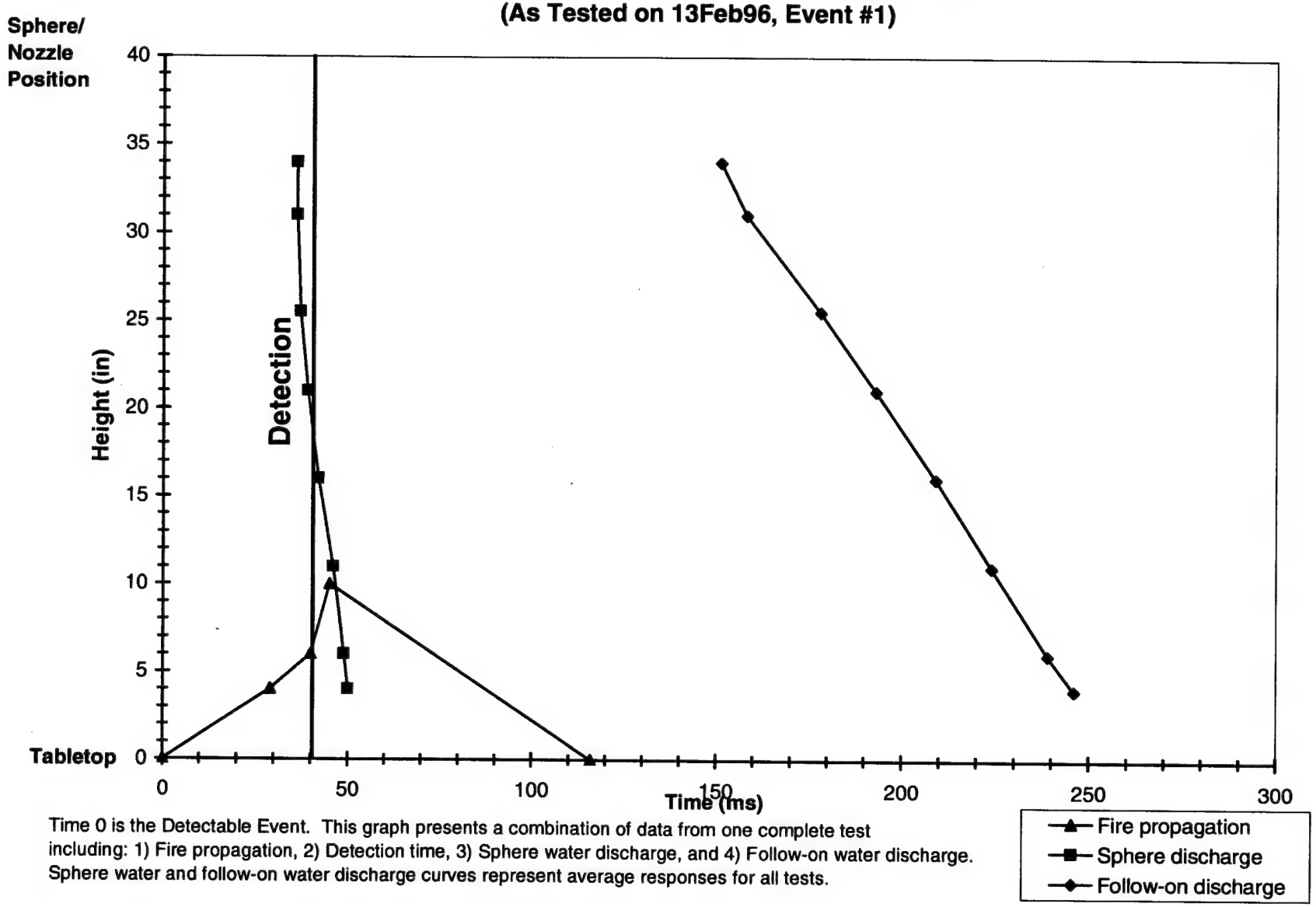
MK 18 Project Load Propagation Rate
(Average Response)



Shows the Average Propagation of MK-18 Project Load flame height from a Detectable Event (time 0) to the maximum flame height before suppression.

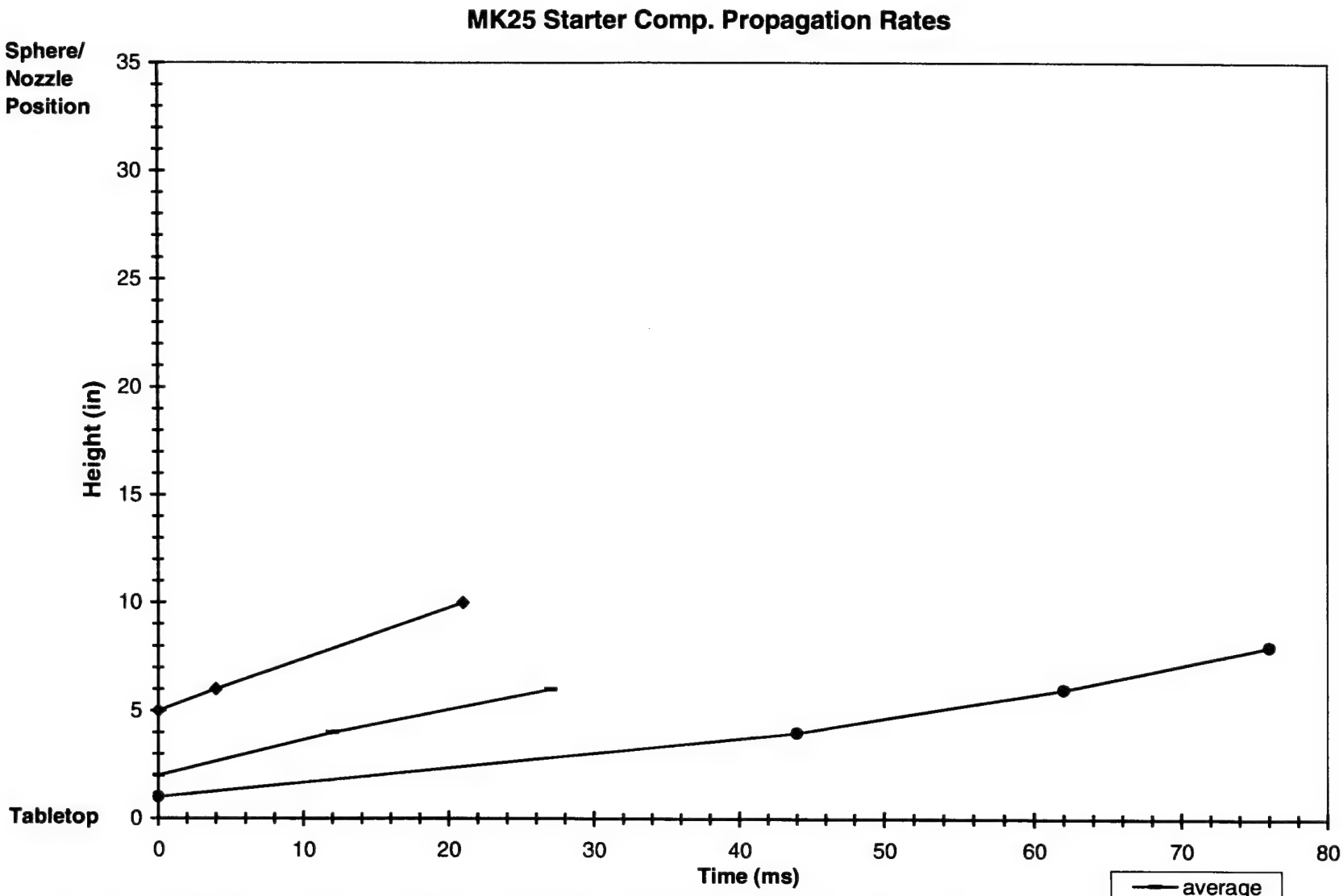
Graph 2

Fire Sentry Detector with 1/4lb MK18 Project Load
(As Tested on 13Feb96, Event #1)



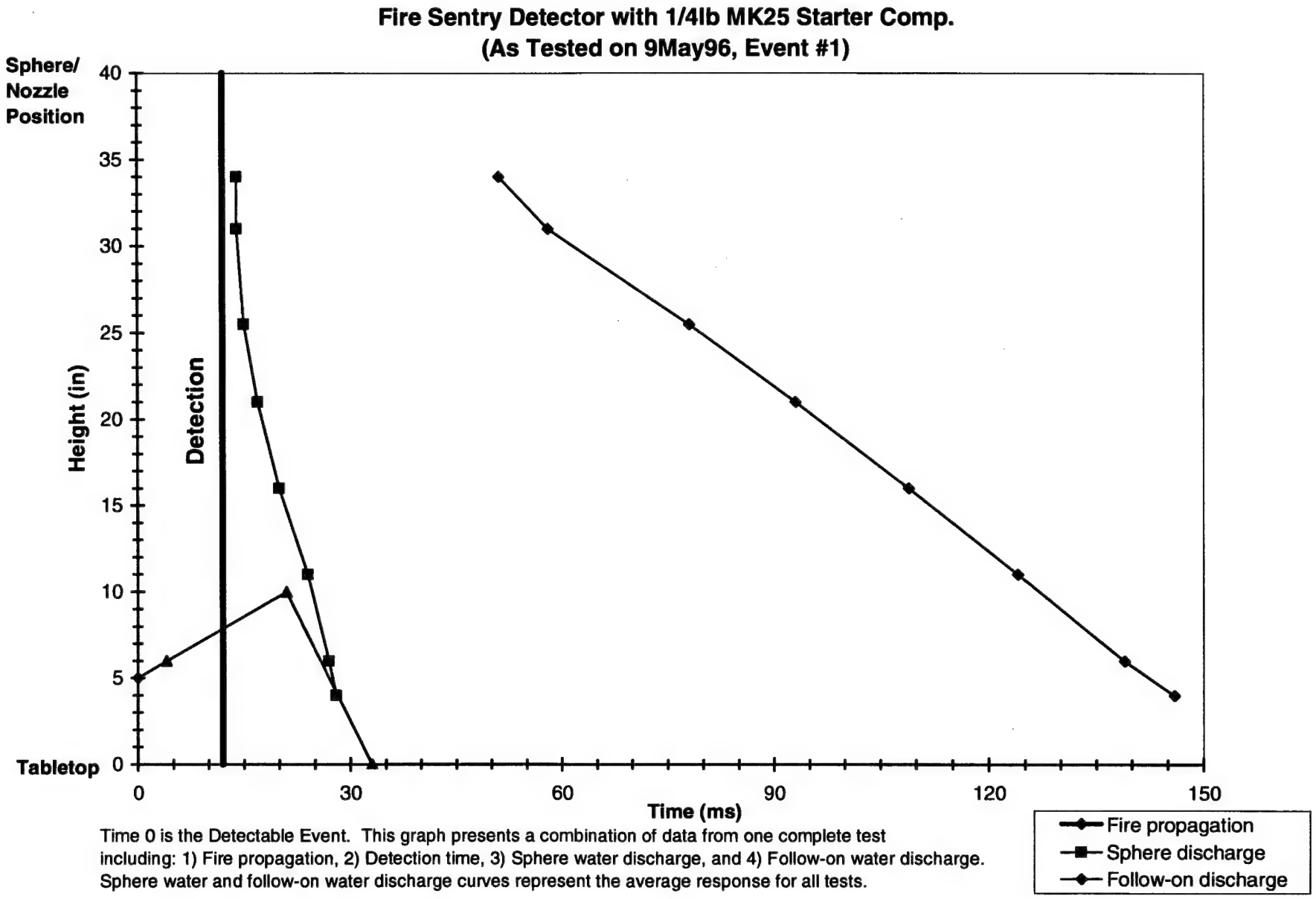
Time 0 is the Detectable Event. This graph presents a combination of data from one complete test including: 1) Fire propagation, 2) Detection time, 3) Sphere water discharge, and 4) Follow-on water discharge. Sphere water and follow-on water discharge curves represent average responses for all tests.

Graph 3



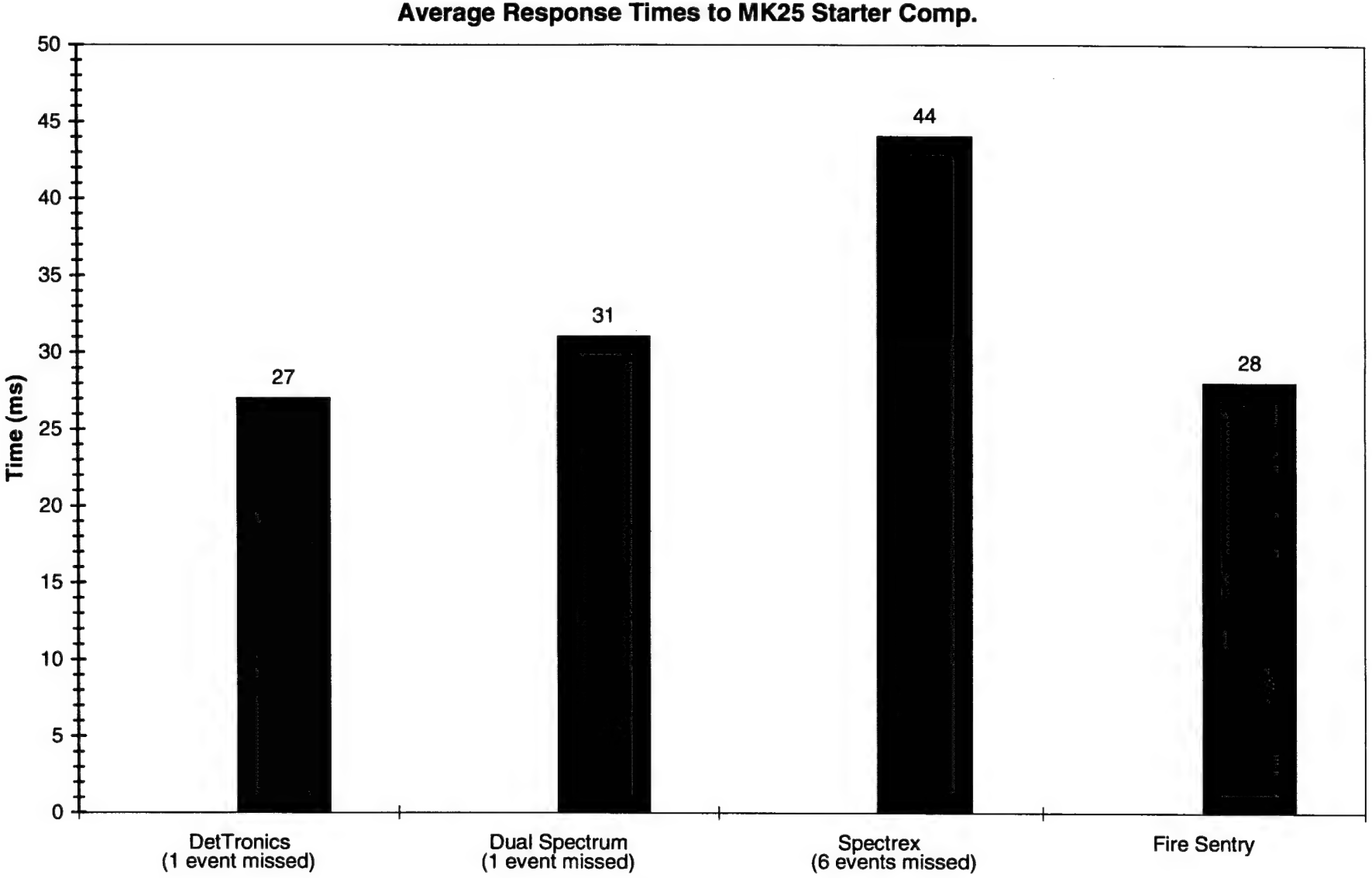
Shows the average, fastest, and slowest propagation rates of MK-25 Project Load flame height from a Detectable Event (time 0) to the maximum flame height before suppression.

Graph 4



Time 0 is the Detectable Event. This graph presents a combination of data from one complete test including: 1) Fire propagation, 2) Detection time, 3) Sphere water discharge, and 4) Follow-on water discharge. Sphere water and follow-on water discharge curves represent the average response for all tests.

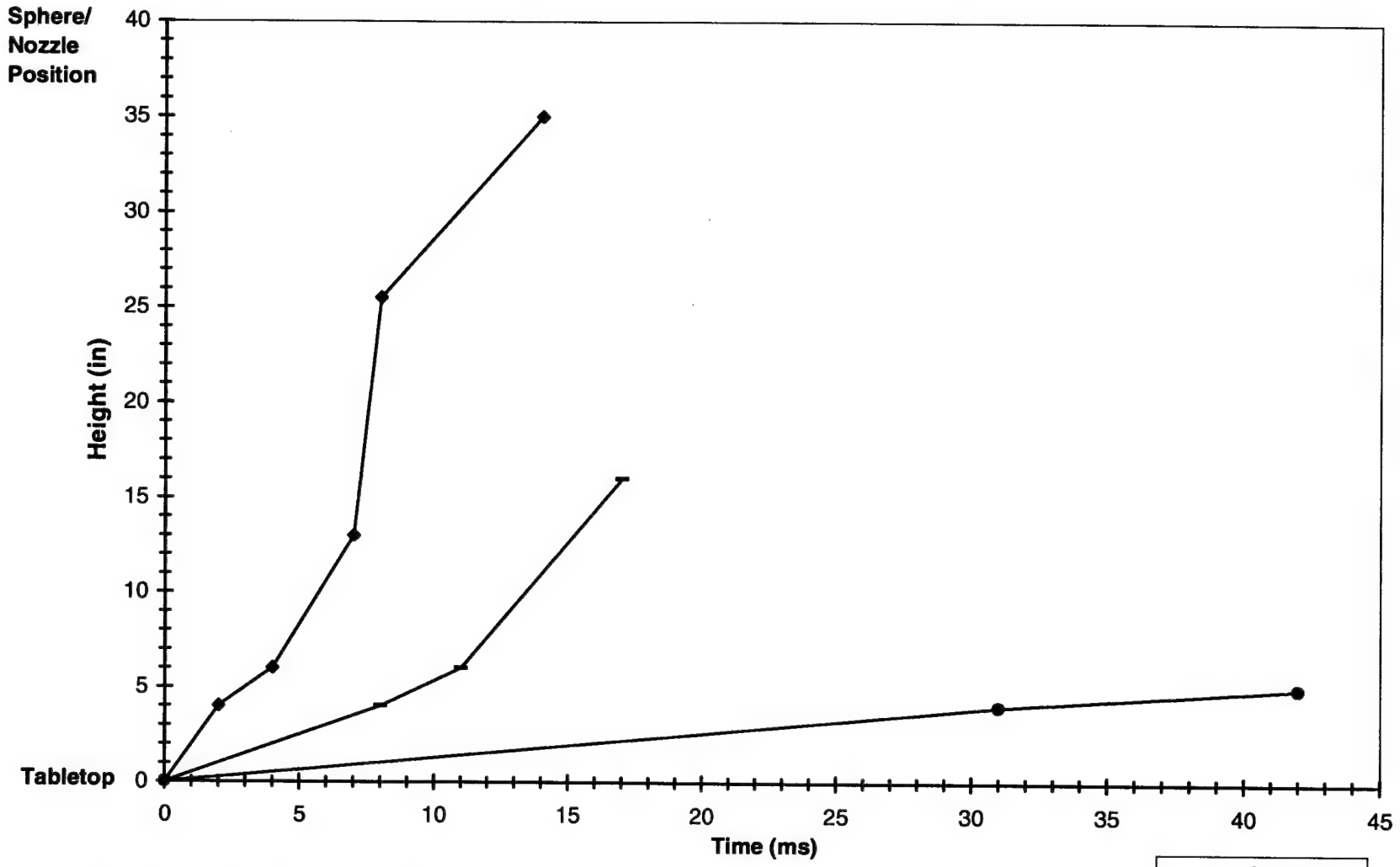
Graph 5



This graph shows each detector's average response time from the detectable event (time 0).
There were ten (10) total events. Events missed were due to water obscuration, see text for details.

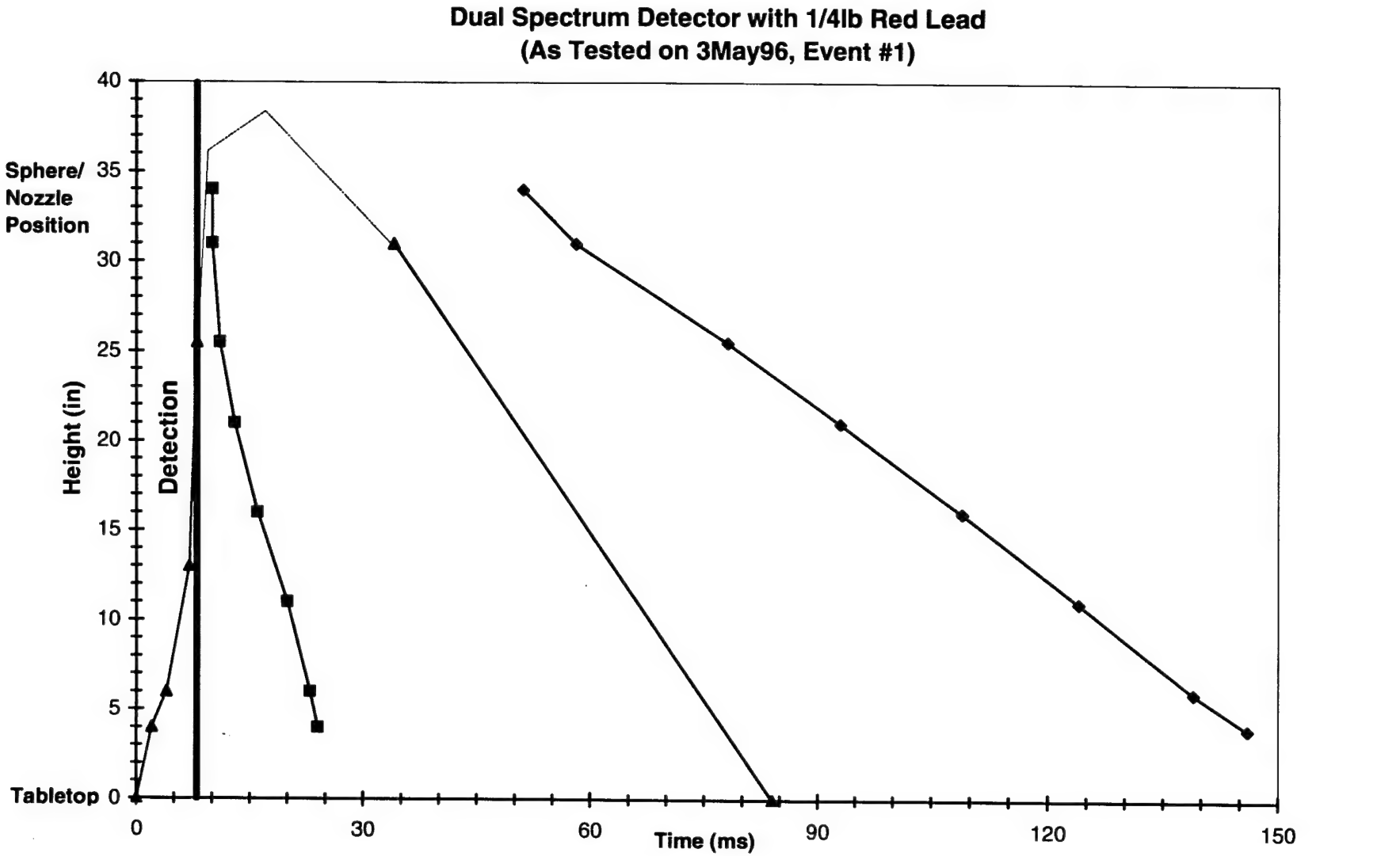
Graph 6

Red Lead Propagation Rates



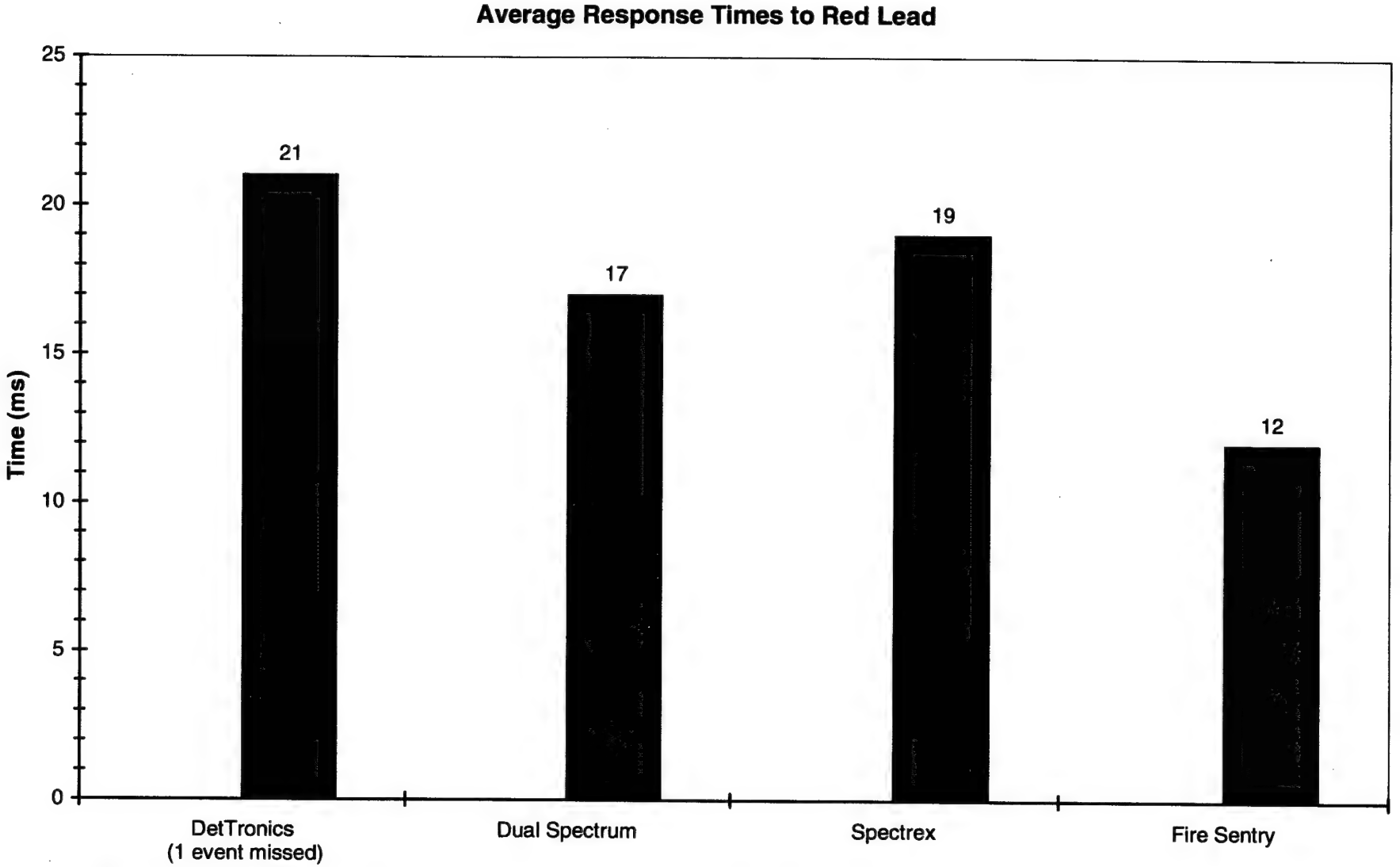
Shows the average, fastest, and slowest propagation rates of Red Lead flame height from the Detectable Event (time 0) to the maximum flame height before suppression.

Graph 7



Time 0 is the Detectable Event. This graph presents a combination of data from one complete test including: 1) Fire propagation, 2) Detection time, 3) Sphere water discharge, and 4) Follow-on water discharge. Sphere water and follow-on water discharge curves represent the average response for all tests. Flame propagation shown as a dotted line is estimated. It could not be measured due to obscuration of the high speed camera.

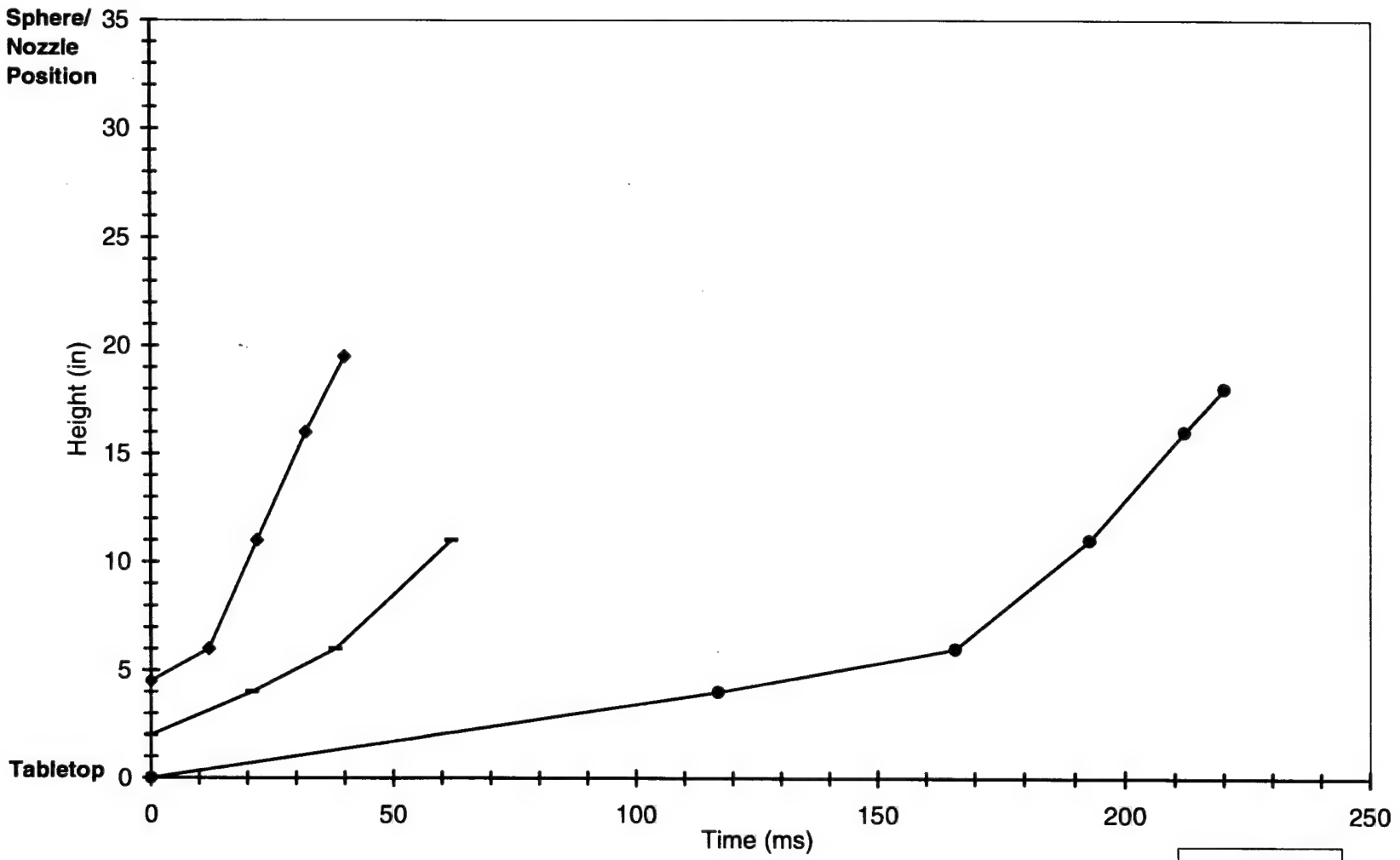
Graph 8



This graph shows each detector's average response time from the detectable event (time 0).
There were fourteen (14) total events. Events missed were due to water obscuration, see text for details.

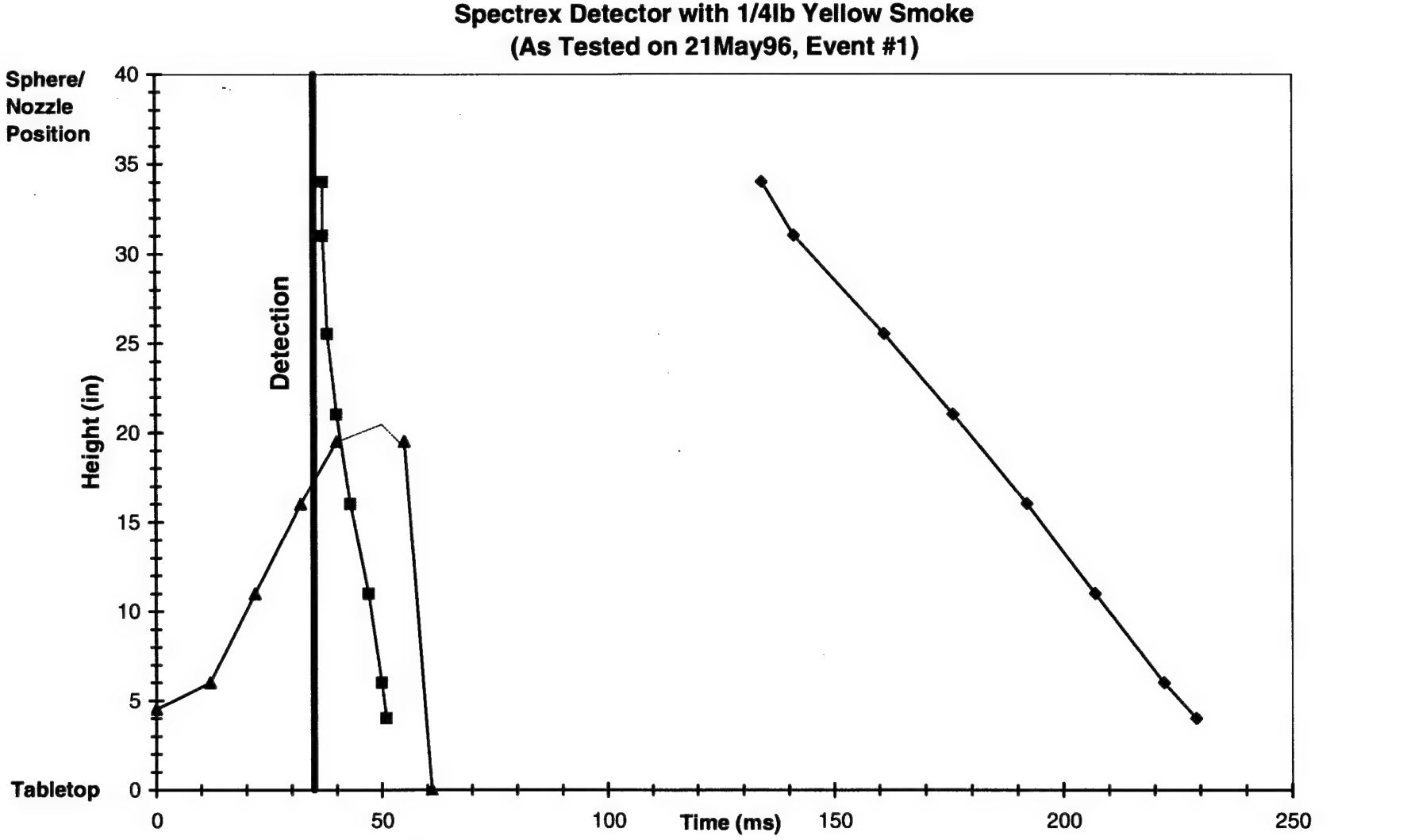
Graph 9

Yellow Smoke Propagation Rates



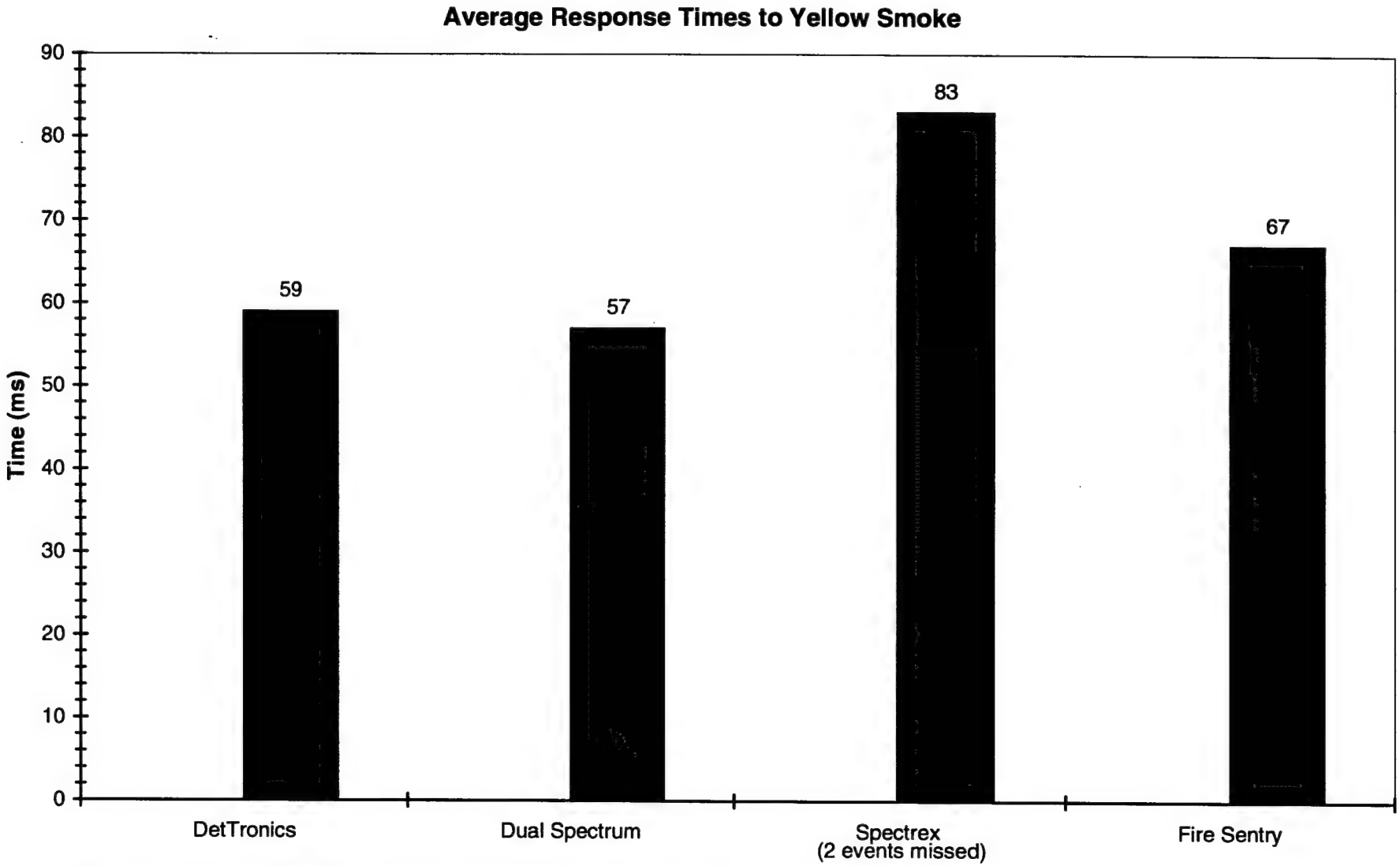
Shows the average, fastest, and slowest propagation rates of Yellow Smoke flame height from the Detectable Event (time 0) to the maximum flame height before suppression.

Graph 10



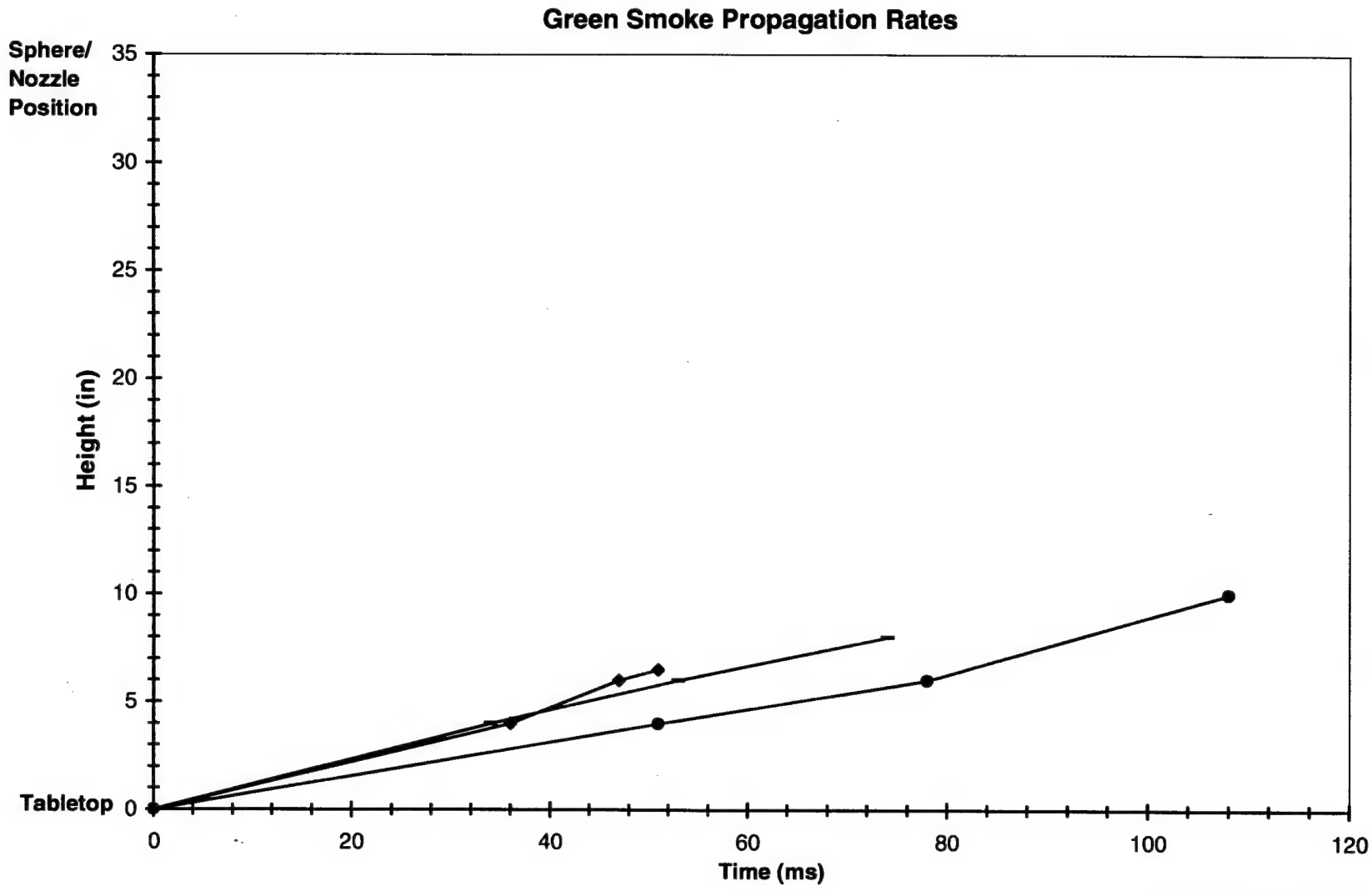
Time 0 is the Detectable Event. This graph presents a combination of data from one complete test including: 1) Fire propagation, 2) Detection time, 3) Sphere water discharge, and 4) Follow-on water discharge. Sphere water and follow-on water discharge curves represent the average response for all tests. Flame propagation shown as a dotted line is estimated. It could not be measured due to obscuration of the high speed camera.

Graph 11



This graph shows each detector's average response time from the detectable event (time 0).
There were nine (9) total events. Events missed were due to water obscuration, see text for details.

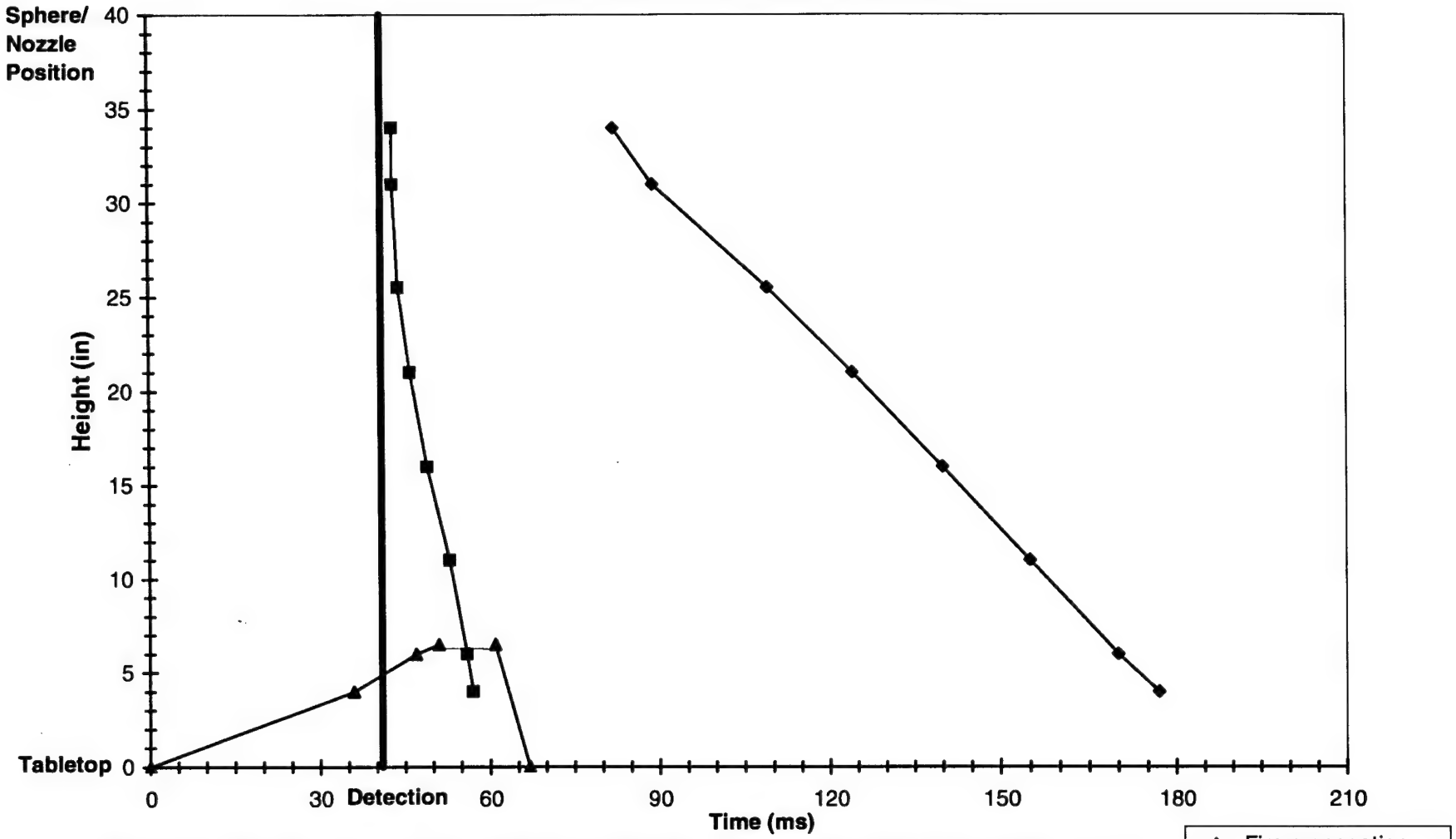
Graph 12



Shows the average, fastest, and slowest propagation rates of Green Smoke flame height from the Detectable Event (time 0) to the maximum flame height before suppression.

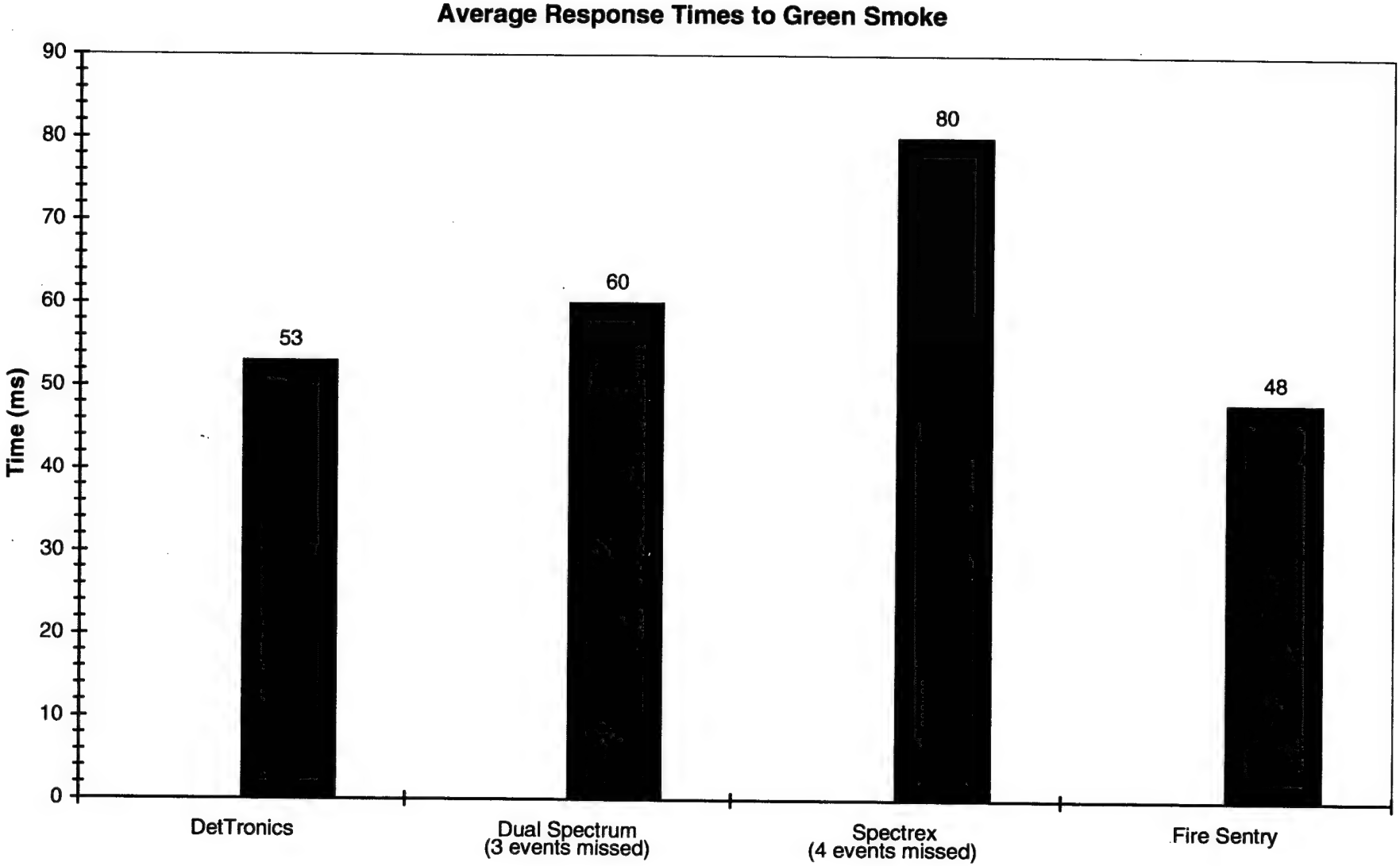
Graph 13

Fire Sentry Detector with 1/4lb Green Smoke
(As Tested on 8May96, Event #4)



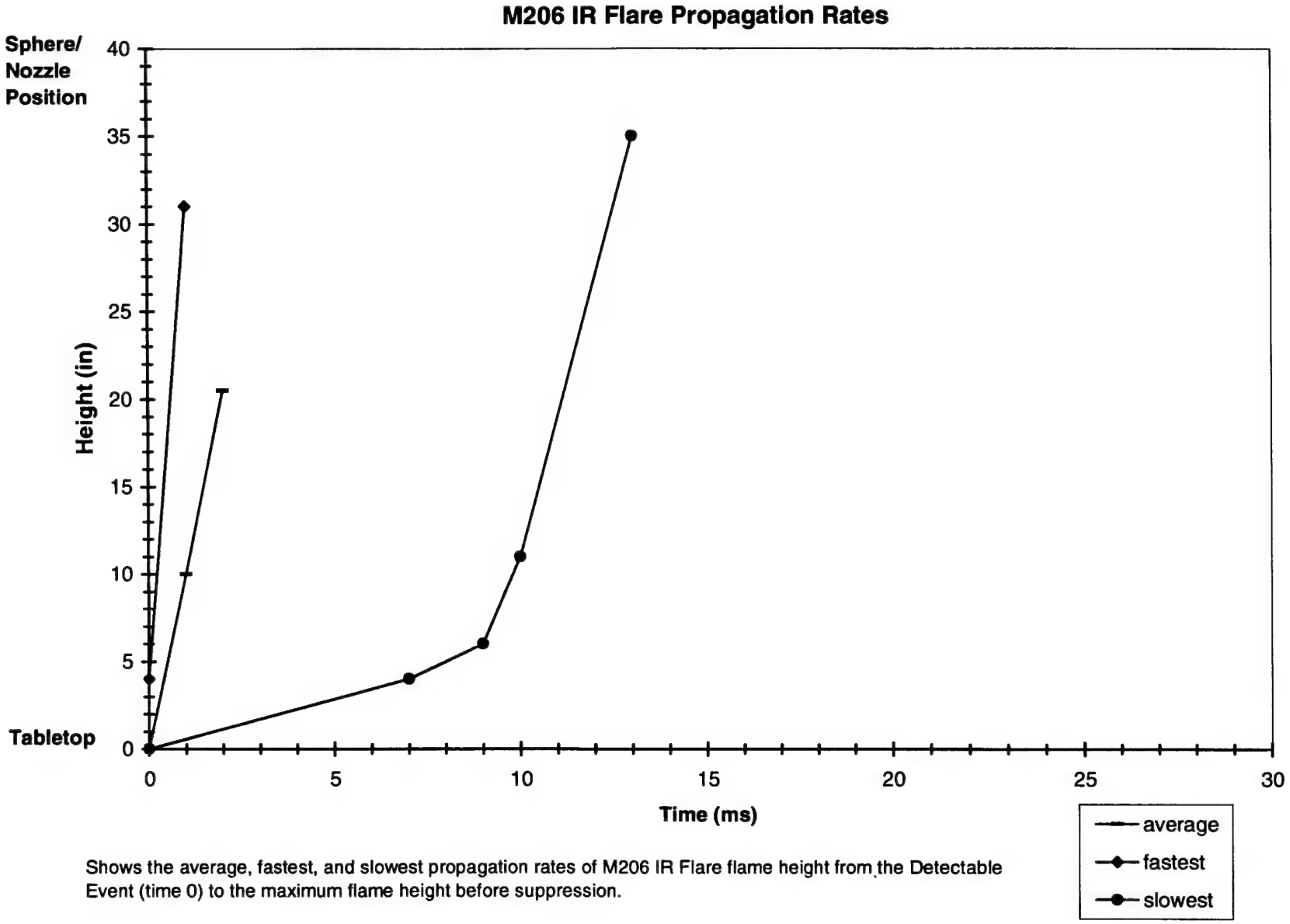
Time 0 is the Detectable Event. This graph presents a combination of data from one complete test including: 1) Fire propagation, 2) Detection time, 3) Sphere water discharge, and 4) Follow-on water discharge. Sphere water and follow-on water discharge curves represent the average response for all tests. Flame propagation shown as a dotted line is estimated. It could not be measured due to obscuration of the high speed camera.

Graph 14



This graph shows each detector's average response time from the detectable event (time 0).
There were twelve (12) total events. Events missed were due to water obscuration, see text for details.

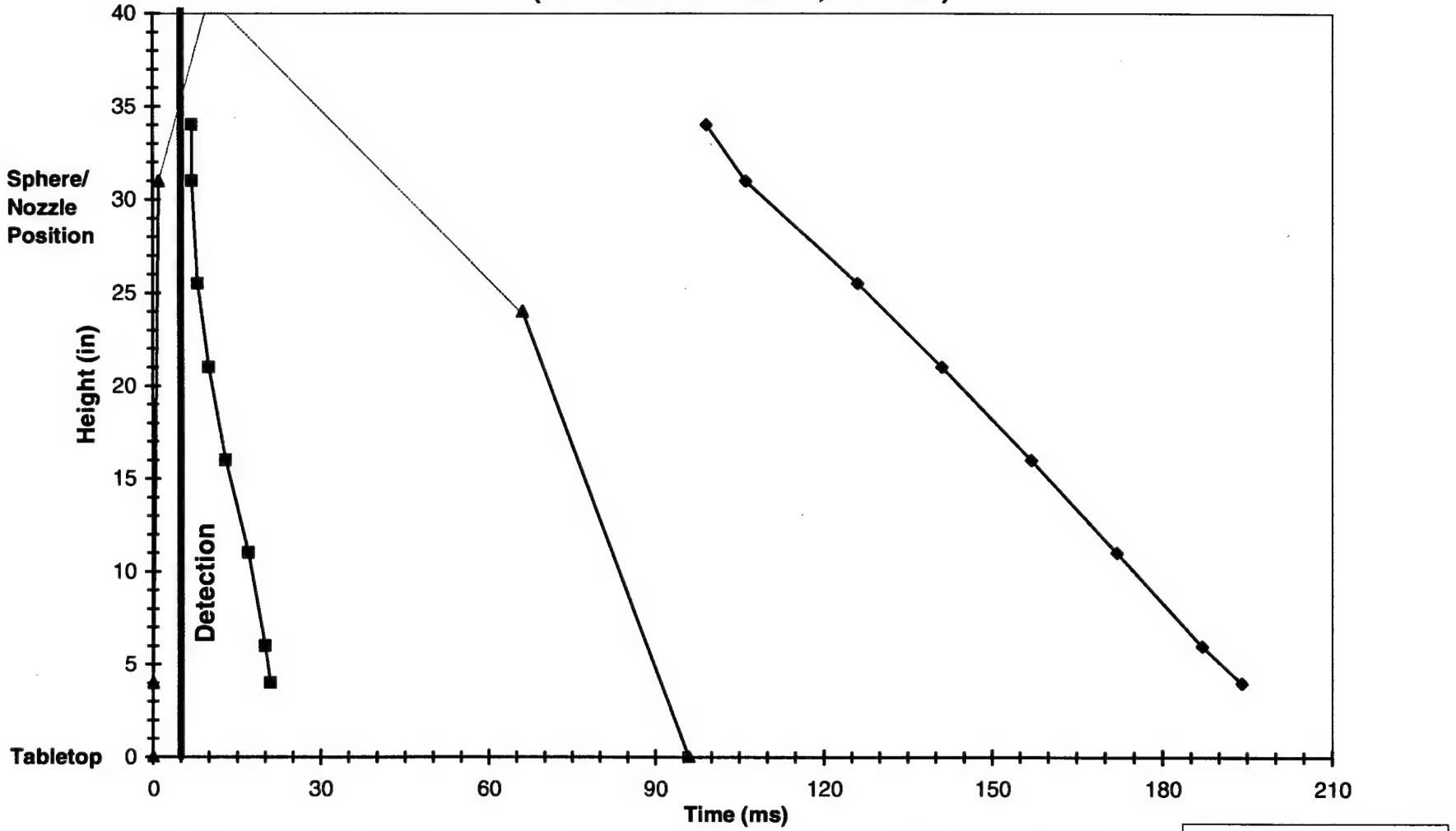
Graph 15



Shows the average, fastest, and slowest propagation rates of M206 IR Flare flame height from the Detectable Event (time 0) to the maximum flame height before suppression.

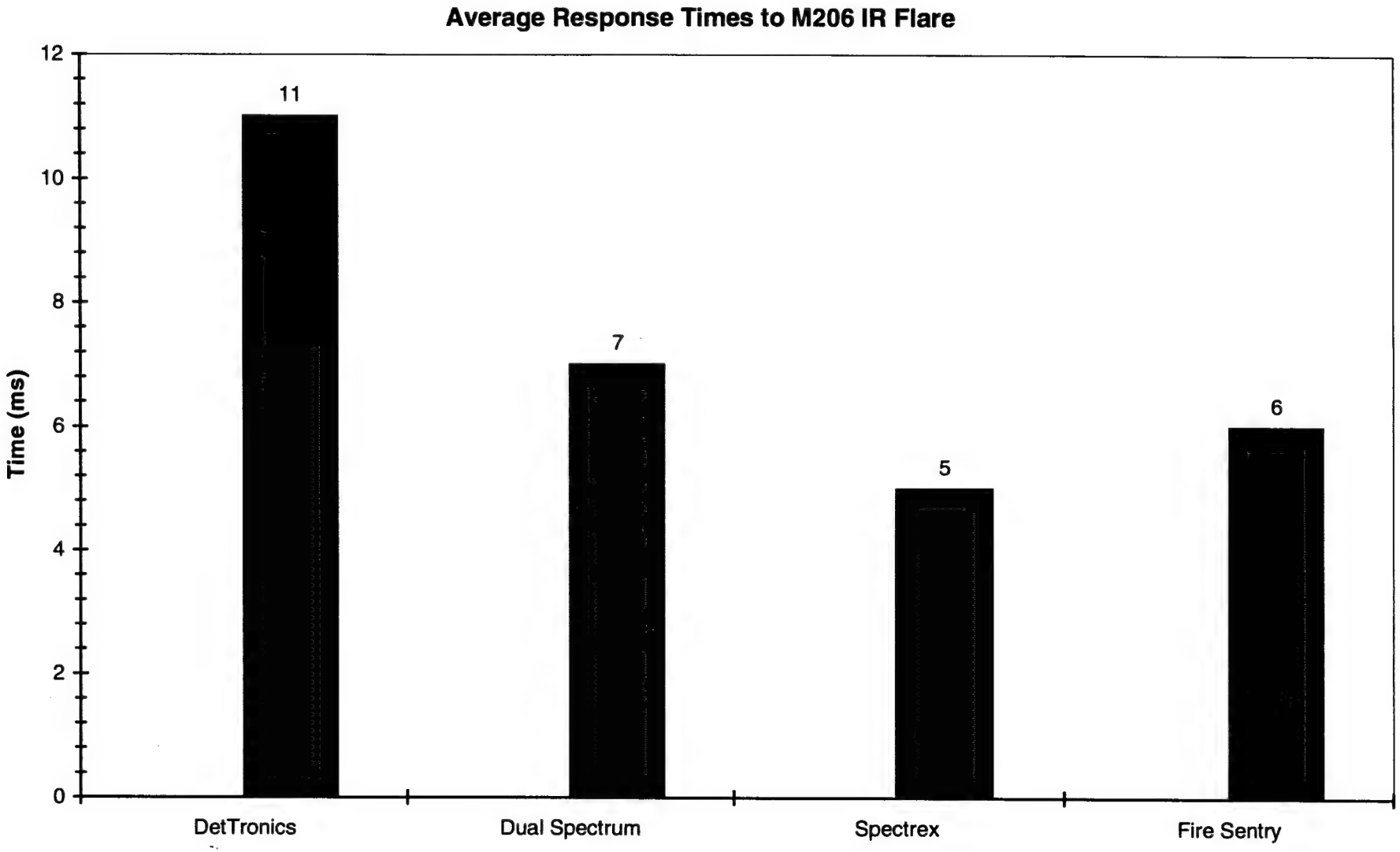
Graph 16

Dual Spectrum Detector with 1/4lb M206 IR Flare
(As Tested on 27Mar96, Event #3)



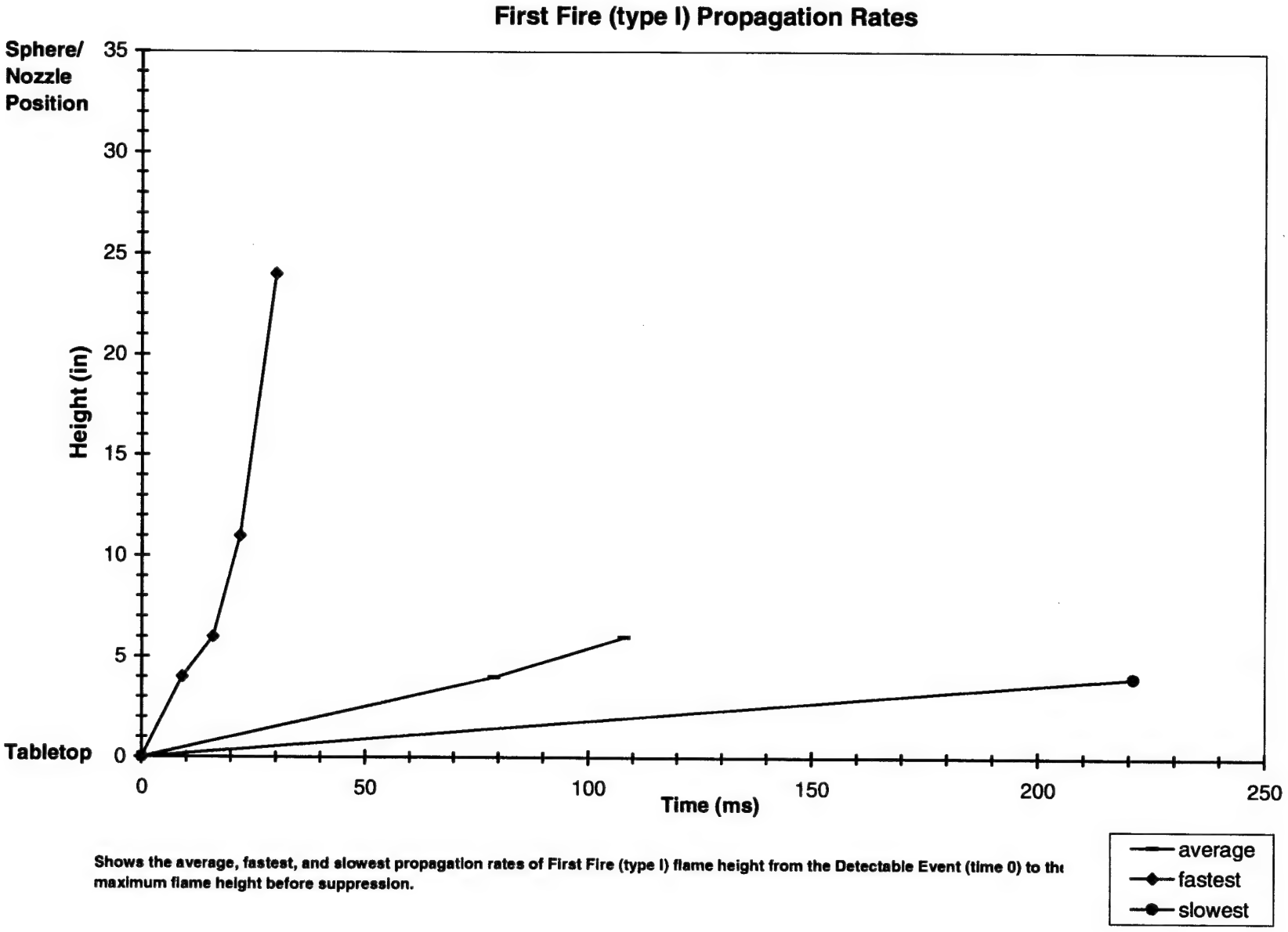
Time 0 is the Detectable Event. This graph presents a combination of data from one complete test including: 1) Fire propagation, 2) Detection time, 3) Sphere water discharge, and 4) Follow-on water discharge. Sphere water and follow-on water discharge curves represent the average response for all tests. Flame propagation shown as a dotted line is estimated. It could not be measured due to obscuration of the high speed camera.

Graph 17



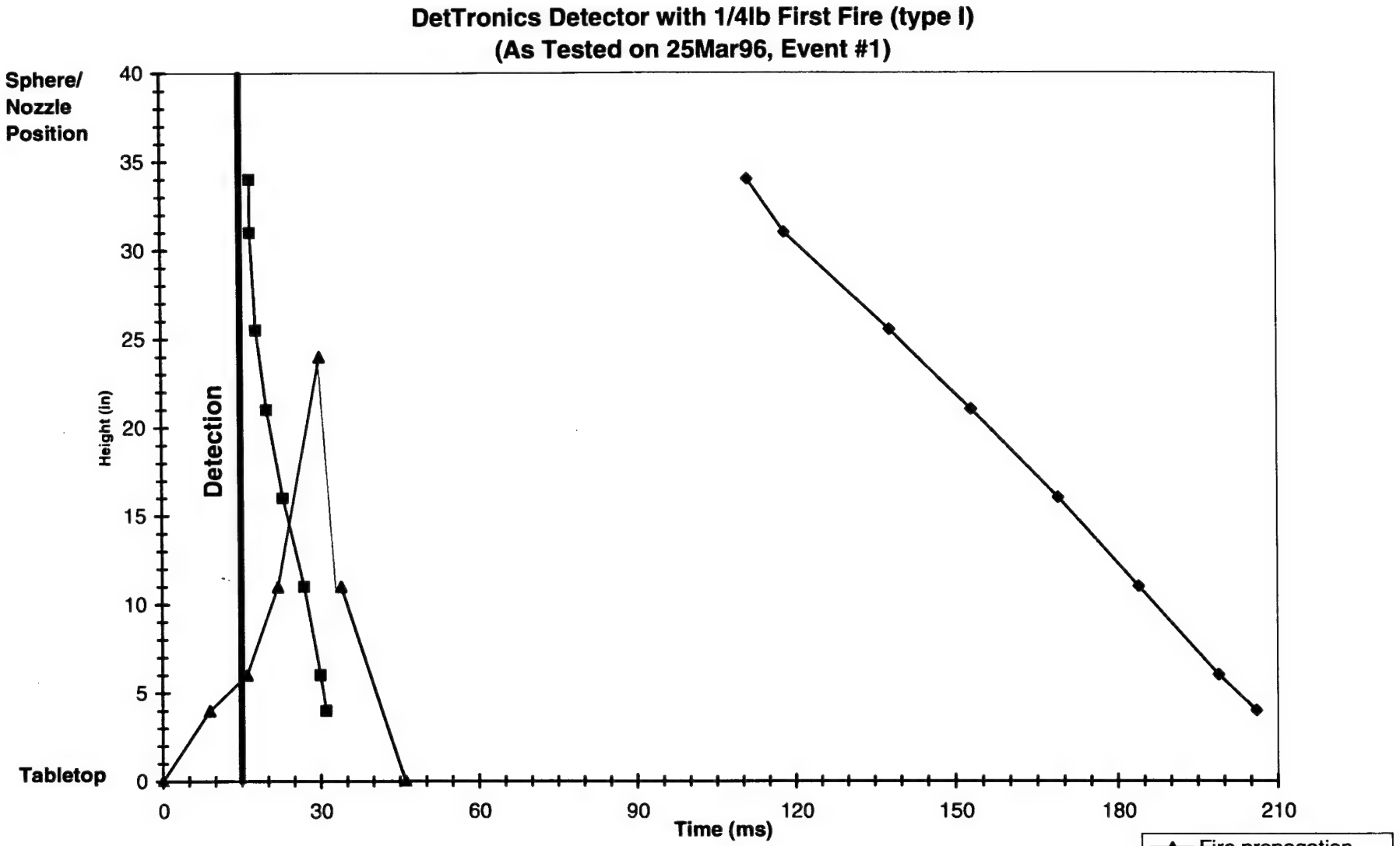
This graph shows each detector's average response time from the detectable event (time 0).
There were nine (9) total events.

Graph 18



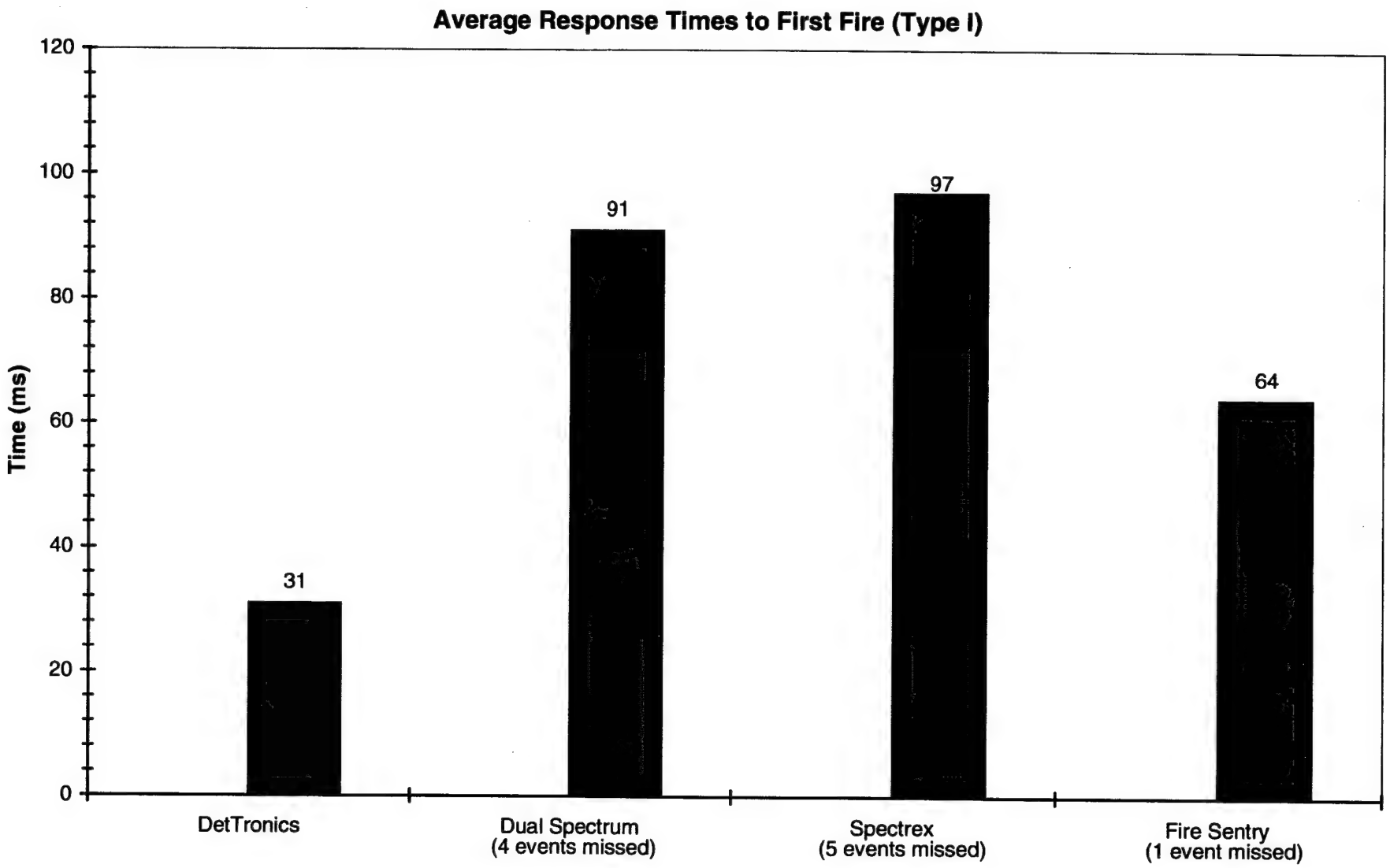
Shows the average, fastest, and slowest propagation rates of First Fire (type I) flame height from the Detectable Event (time 0) to the maximum flame height before suppression.

Graph 19



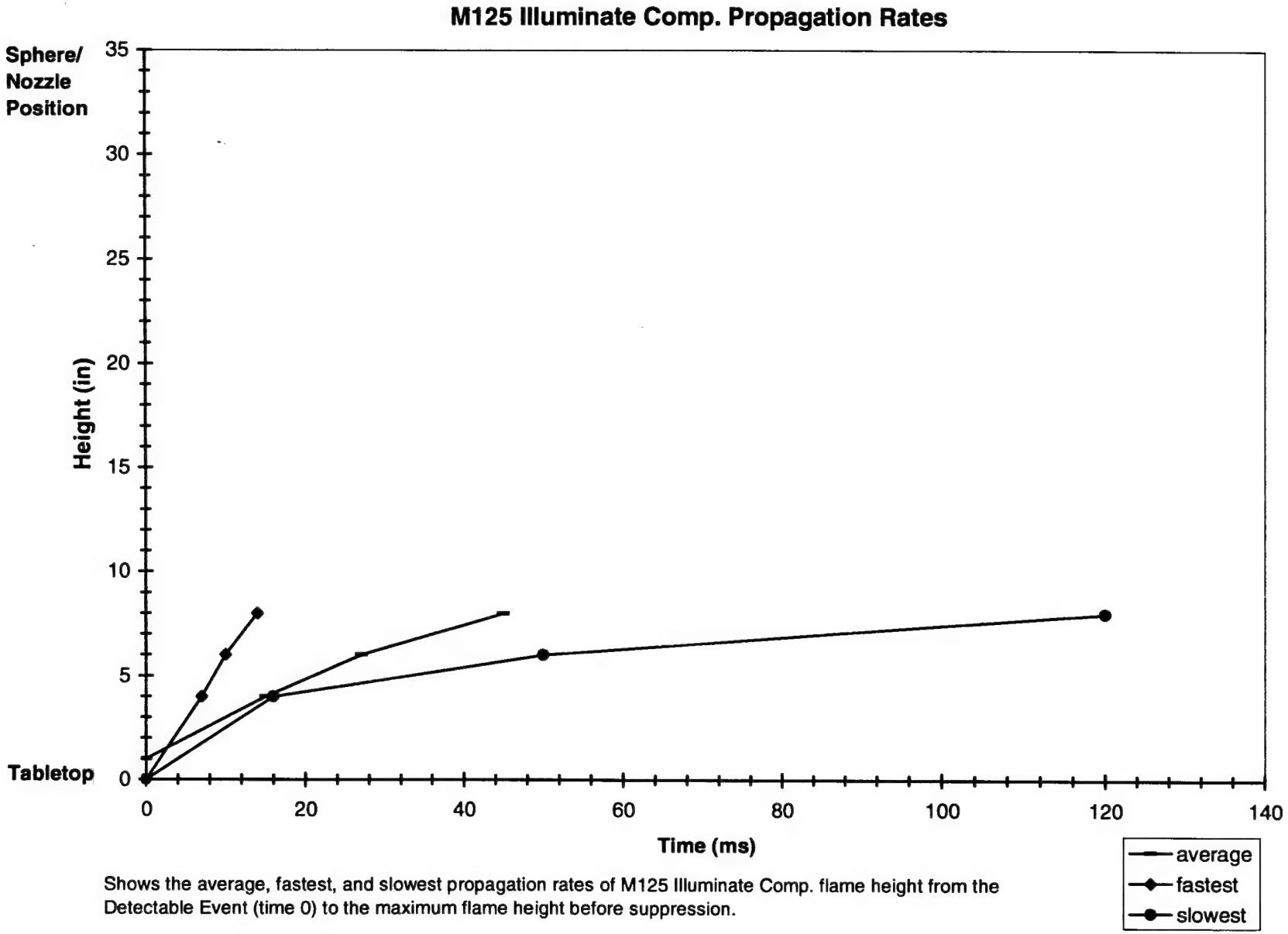
Time 0 is the Detectable Event. This graph presents a combination of data from one complete test including: 1) Fire propagation, 2) Detection time, 3) Sphere water discharge, and 4) Follow-on water discharge. Sphere water and follow-on water discharge curves represent the average response for all tests. Flame propagation shown as a dotted line is estimated. It could not be measured due to obscuration of the high speed camera.

Graph 20



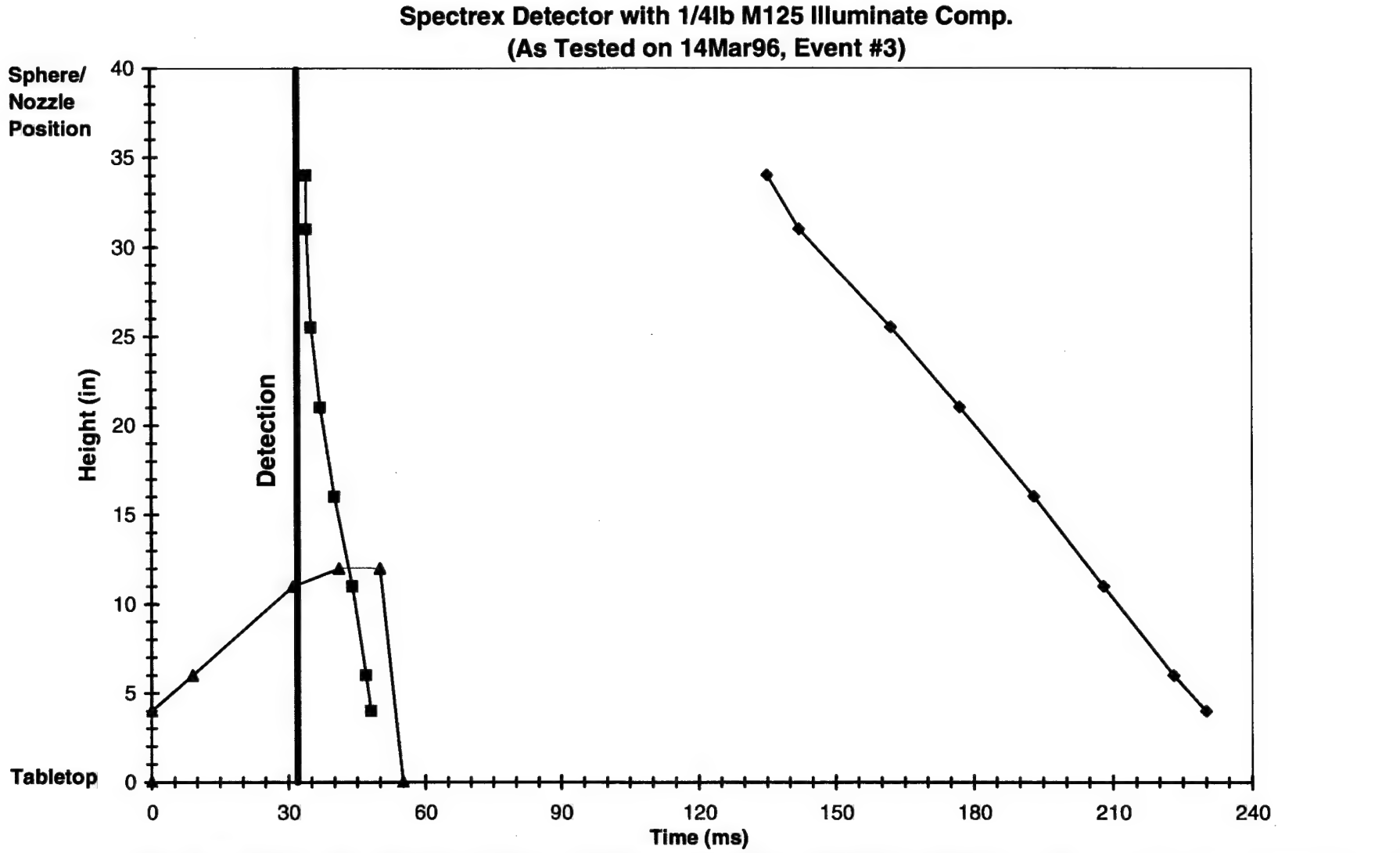
This graph shows each detector's average response time from the detectable event (time 0).
There were ten (10) total events. Events missed were due to water obscuration, see text for details.

Graph 21



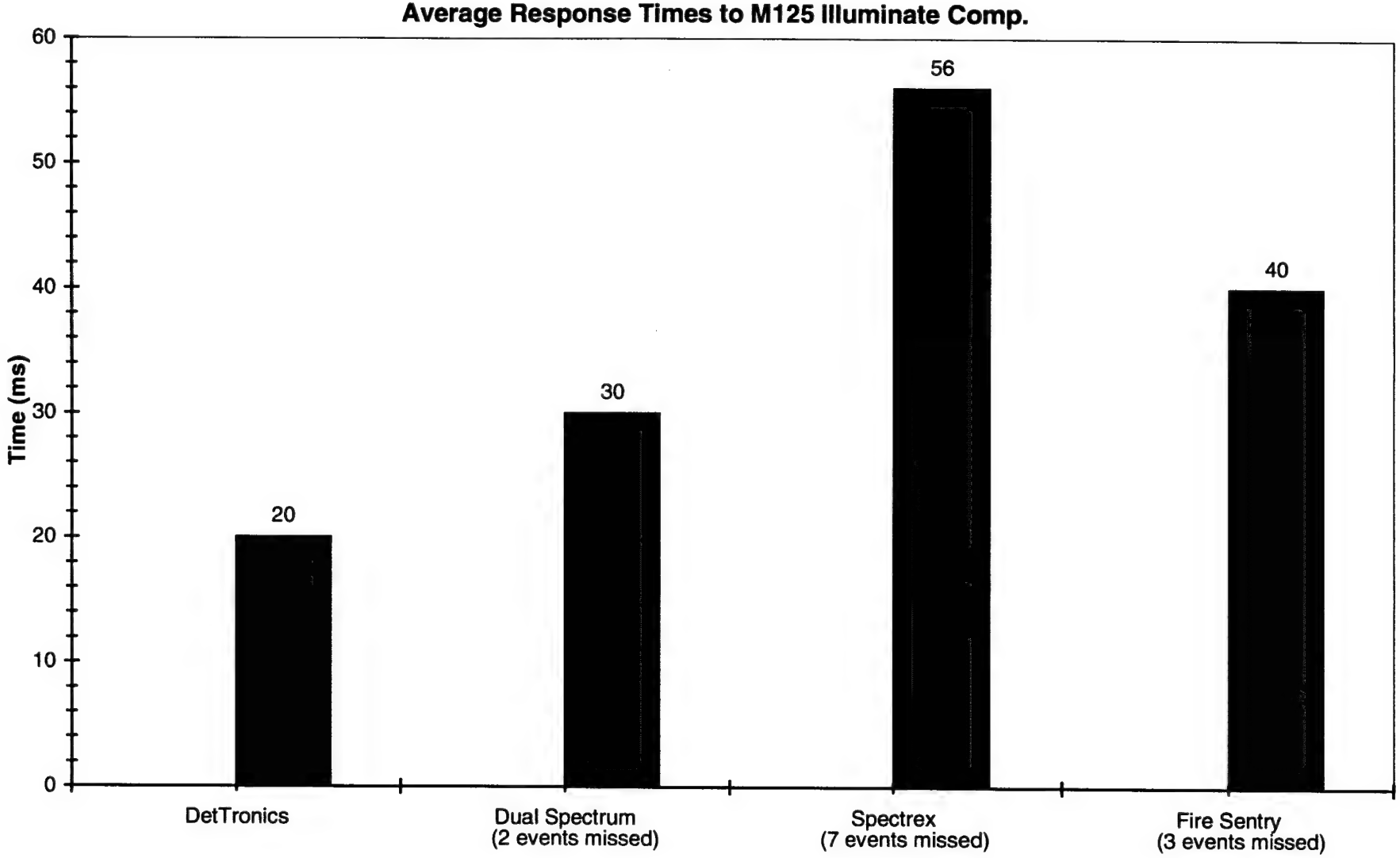
Shows the average, fastest, and slowest propagation rates of M125 Illuminate Comp. flame height from the Detectable Event (time 0) to the maximum flame height before suppression.

Graph 22



Time 0 is the Detectable Event. This graph presents a combination of data from one complete test including: 1) Fire propagation, 2) Detection time, 3) Sphere water discharge, and 4) Follow-on water discharge. Sphere water and follow-on water discharge curves represent the average response for all tests. Flame propagation shown as a dotted line is estimated. It could not be measured due to obscuration of the high speed camera.

Graph 23



This graph shows each detector's average response time from the detectable event (time 0).
There were twelve (12) total events. Events missed were due to water obscuration, see text for details.

Graph 24

APPENDIX 2

FALSE ALARM STIMULI TESTING

A critical task associated with this project was to find a false alarm immune optical detector that was fast enough to operate a munitions fire suppression system with a high degree of confidence. In a broad area announcement search of existing technology only three manufacturers claimed to possess such detectors at the start of testing. Two of these detectors had been used in combat tested tanks and armored personnel carriers. Although claims were made by the manufacturers representatives, false alarm stimuli tests had to be conducted to validate these assertions. The detectors tested included:

a. Det Tronics R7303, C7050B combination UV fire detection system (baseline)

b. Dual Spectrum PM-5SX fire sensor (IR/IR)

c. Spectrex model 620002 (UV/IR)

d. Fire Sentry model SS2-A multi-spectrum flame detector

A single detector from each manufacturer was mounted on a 20 inch X 20 inch sheet of plywood at right angles to the board and in close proximity to each other. This mounting configuration ensured that each of the four detectors were viewing the event from essentially the same position. The alarm outputs of each detector were wired to a latching circuit designed to indicate and record when a particular detector alarmed.

Several false alarm stimuli sources representing the most common causes found at plants and arsenals were duplicated. These stimuli included floodlights, flash lights, neon drop lights, butane lighters, grinders, an acetylene torch, incandescent lights, fluorescent lights, flash cameras, sun light, chopped light (flood light and drop light sources), drill motor (sparking), MIG and stick welding (mild steel, aluminum, and stainless steel) with various currents and rods (see Figure 2-1). A high voltage, low current electric arc was also tested against the detectors. The detectors were exposed to the false alarm source, located directly in front of the units for 30 seconds at each specified distance. Alarms from any of the four (4) detectors were noted.

Figure 2-1 - False Alarm Stimuli

Distances from the detectors to the source of less than 6 inches required placing the source directly in front of an individual sensor, then repeating the test at the same distance with each detector. Even a single detector false alarm would be indicated at the specific distance on the following graphs. Several false alarm stimuli were

introduced with a large rotating fan placed between the detector and the source. The "chopped" light frequency was 0-5 Hz and was used to simulate a person breaking the light source and detector line-of-sight (see Figure 2-2). This action can produce a flickering fire effect and cause detectors to false alarm. Most false alarm stimuli testing was also conducted at an angle of 45° from detector line of sight. The detector performance characteristics are graphically displayed in graphs 25 through 36. Comments are provided for some graphs, however most are self explanatory. The results are also summarized in Table 2. Unless otherwise indicated, all sources were exposed to the detectors for a period of 30 seconds.

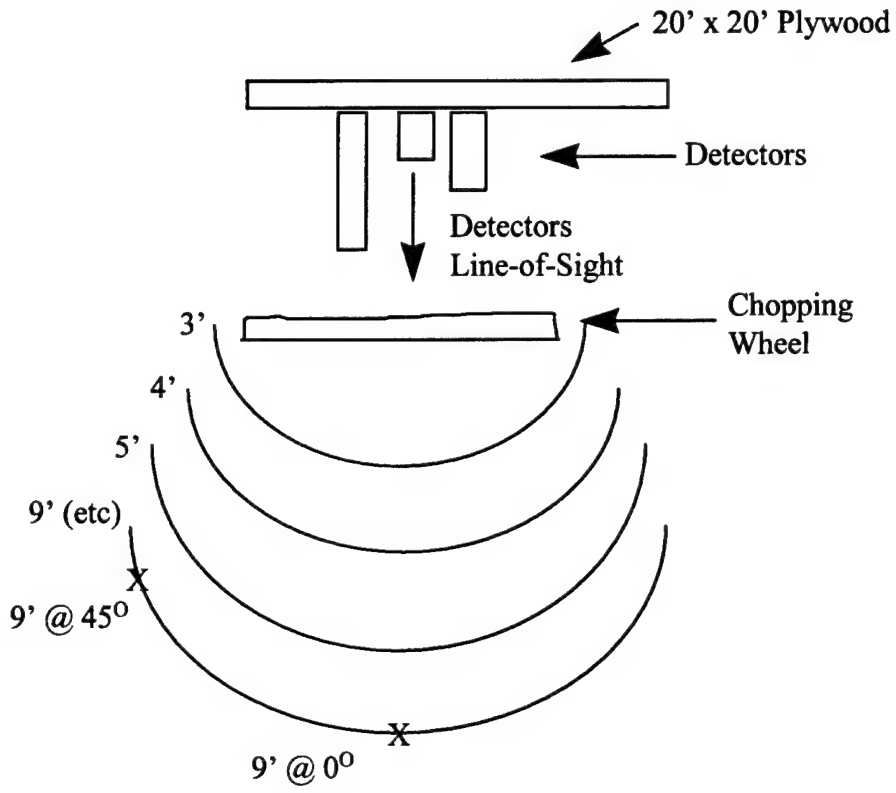


Figure 2-2
False Alarm Testing Setup

It should be noted that some false alarm stimuli did not create a reaction with any of the four detectors. These stimuli were:

a. Drop light, 120V A/C 15W. Source was placed in front of each detector at a distance of one inch for three tests each. Light was moved around in front of the detector at varying positions and angles. None of the detectors alarmed, so the test was terminated.

b. Military issue flashlight (Fulton MX 992 lu). Light was placed at one inch distance from each detector to include 45° and 90° positions repeated three times each. Light was also turned off and on rapidly, using signal button, in front of each detector. These same tests were repeated with the background lights turned off. None of the detectors alarmed, so the test was terminated.

c. Sunlight (reflected off mirror). Three tests per detector were completed with the light reflected into the detector at 0^{o}, with the mirror steady for 30 seconds and flickering. This was accomplished at a distance of 24 feet from the detectors (outside the test facility door at noontime hours). Each test was also repeated with the room background lights turned off. None of the detectors reacted to these false alarm stimuli.

d. Flash Camera (Cannon Sure Shot). All testing was done at 2', 3', and 8' intervals (0^{o} and 45^{o}). The camera did not activate any of the four detectors.

Note: Several tests were conducted with the stimuli source only one inch from the detector. Upon reflection it was decided that this data may not reflect a realistic situation. However, the charts depicting these tests are included as graphs 28 and 29. This action had no effect on the conclusions outlined below. The tests shown on graphs 28 and 29 are the Philips Earthlight (17W, fluorescent) and 75W floodlight respectively.

Four separate welding tests produced the same results as Graph 33, Arc Welding with 1/8" Palco 680 rods, welding AL Alloy at 104A. These test were:

1. 3/32" nickel rods, ss plate, 56A
2. 308L ss rods, ss plate, 56A
3. 3/32" 6011 rods, mild steel, 56A
4. 1/8" 7018 rods, mild steel, 124A

Note: Besides not false alarming to welding sources at distances greater than 6 feet, the three multi-spectrum detectors tested were all able to successfully detect a flame while welding was present 12 feet away.

CONCLUSIONS

a. Testing confirmed that the existing UV baseline detector is susceptible to many false alarm stimuli. It should be noted however that the UV detector did not react to a 120V A/C 15W Fluorescent droplight, flashlight, sunlight (with mirror), flash camera, 17W Philips Earthlight (fluorescent), 75W floodlight and mild steel grinding . The detector faulted on several occasions but did not alarm.

b. For the Phase I testing the Spectrex model 620002 was virtually immune to every false alarm stimuli tested. The only time the unit alarmed was once at three feet with the lighting of an acetylene torch (an actual fire).

c. The Dual Spectrum PM-5SX fire sensor (IR/IR) was the second best performing detector in the false alarm stimuli tests conducted in Phase I of the project. It alarmed to low powered light sources at very short distances (under 6 inches) when the other units did not.

However, this is not deemed to be a problem in a real life situation. It also alarmed to a butane lighter at six inches, arc welding at three feet and an acetylene torch at three feet.

d. Although performing very well in seeing and reacting to a munitions fire, the Fire Sentry SS2-A multi-spectrum fire detector did not perform as well in the false alarm stimuli tests as the Spectrex and Dual Spectrum units.

e. False alarm overall ratings:

#1: Spectrex

#2: Dual Spectrum

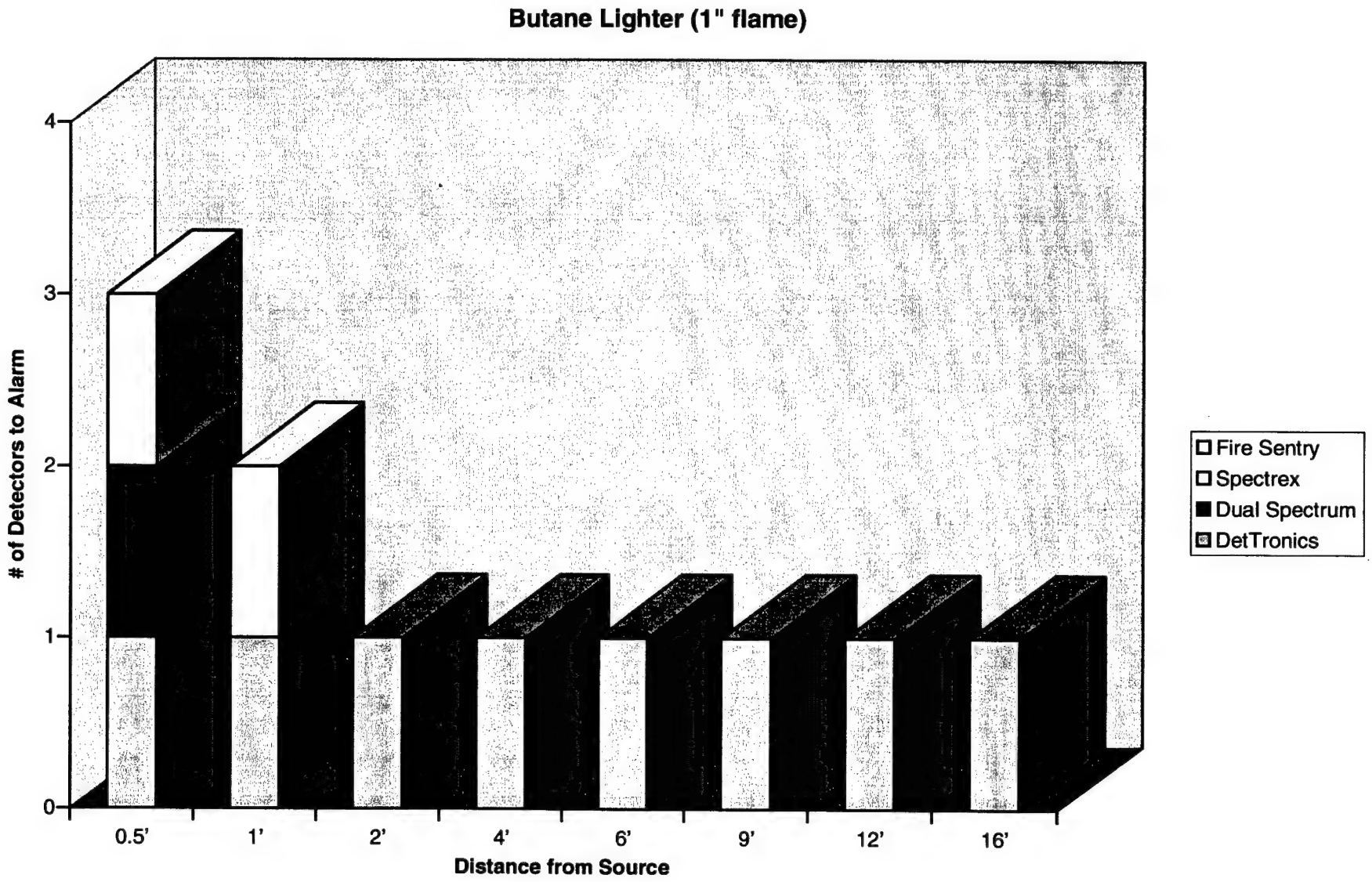
#3: Fire Sentry

#4: Det Tronics

- Spectrex and Dual Spectrum did very well, not alarming to any false alarm source over 3 feet away.

- Fire Sentry did not alarm to any event over 6', except the acetylene torch at 12' which is itself a real fire.

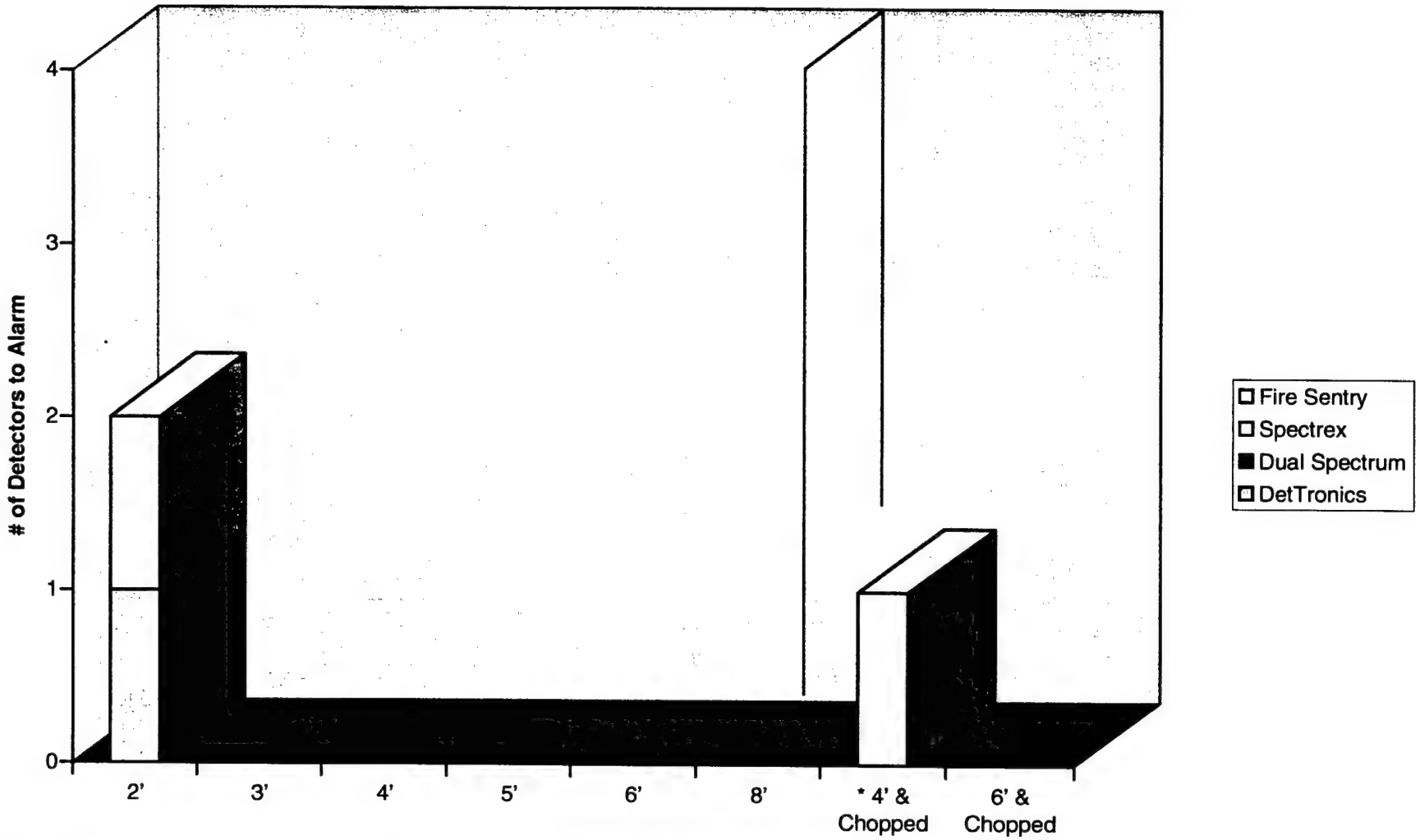
- Det Tronics alarmed consistently to many sources at great distances, the farthest distance not being recorded because of space limitations. Det Tronics also alarmed to a welding source reflected off of a painted wall, not in direct line-of-sight.



*** Lighter was exposed to detectors for 10 sec. each test in order to generate an alarm**

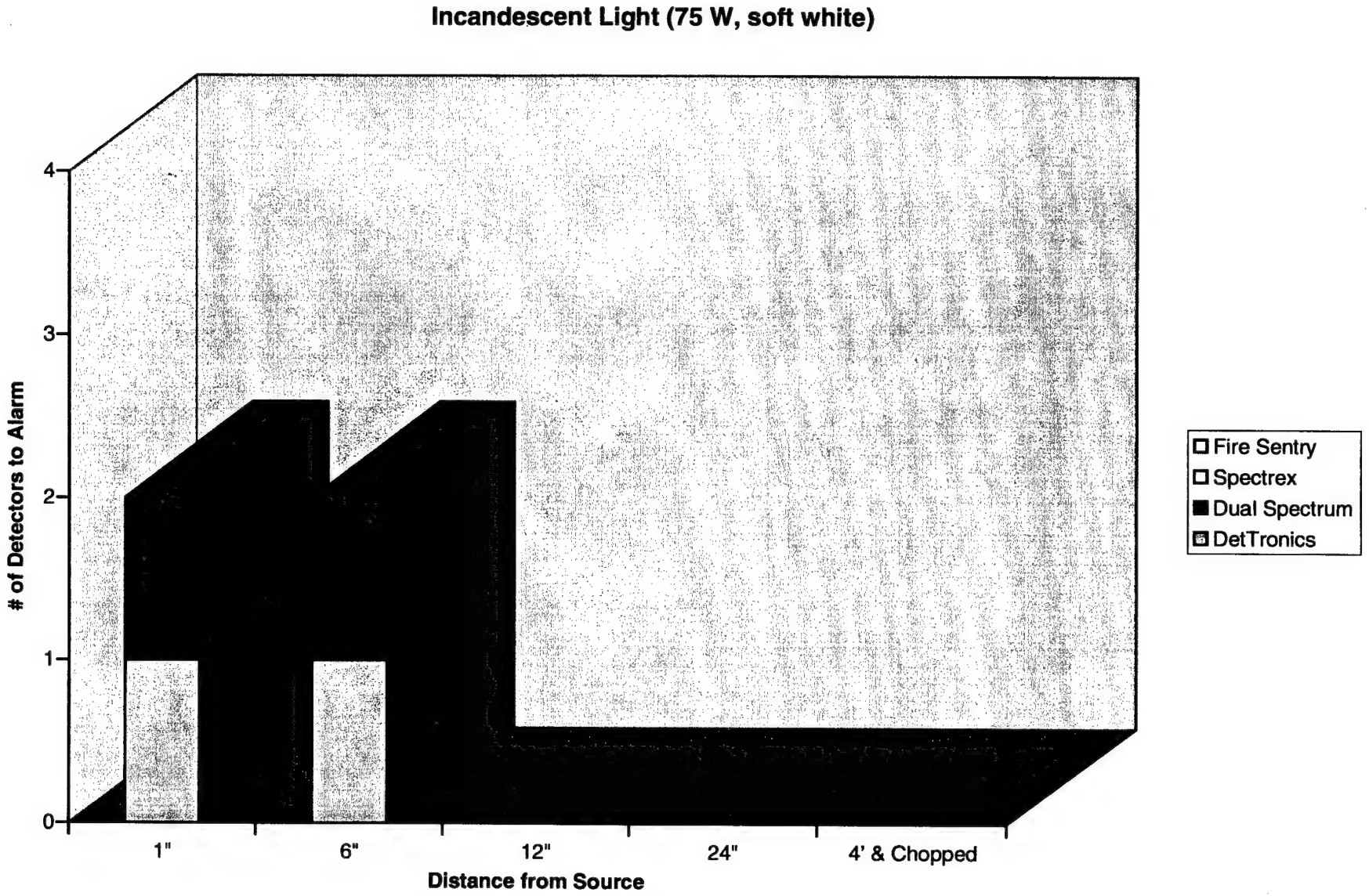
Graph 25

Floodlight (quartz lens, 650W)

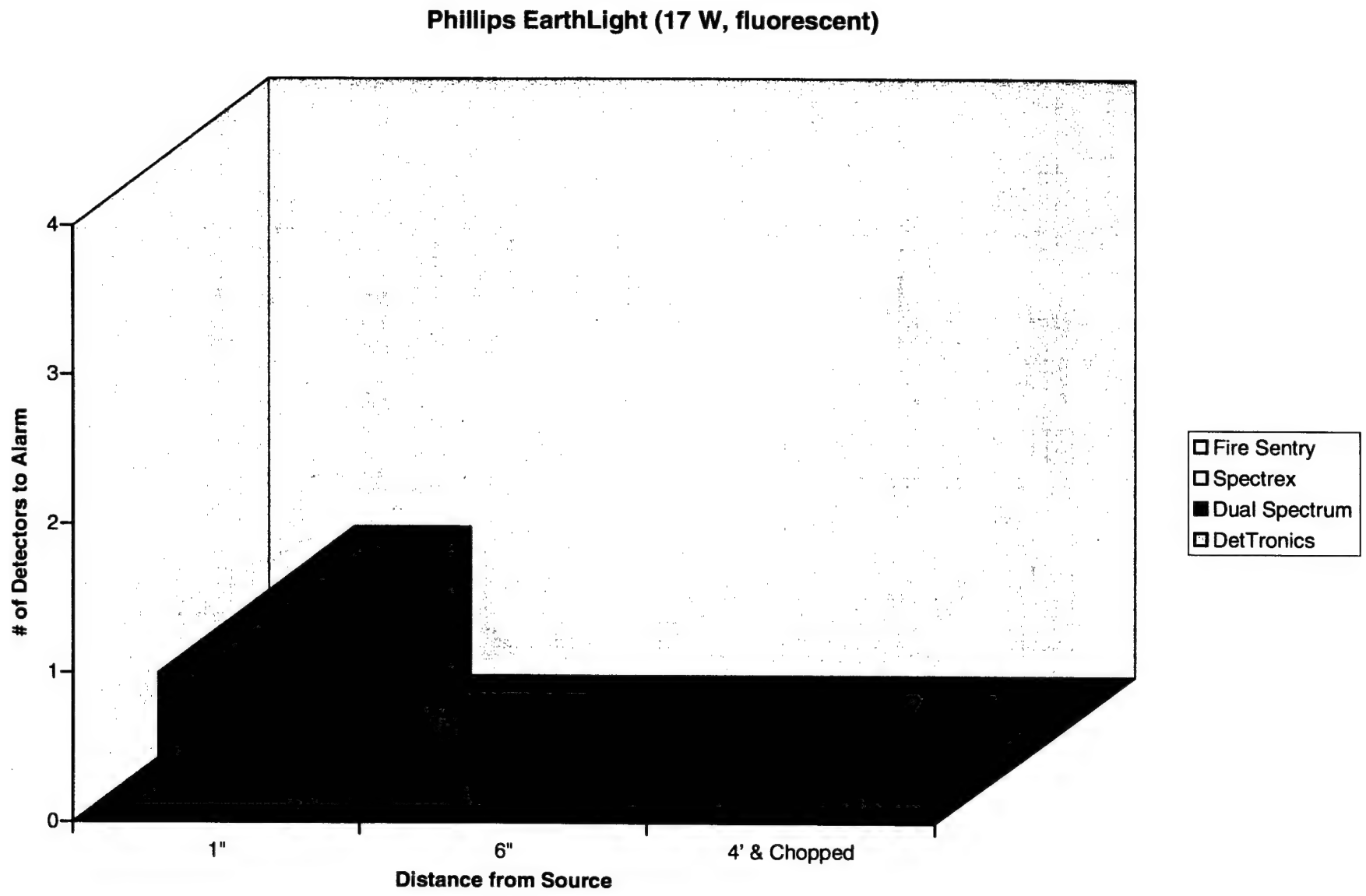


*** Four feet was determined to be the minimum distance wherin people would be expected to walk between the source and detector**

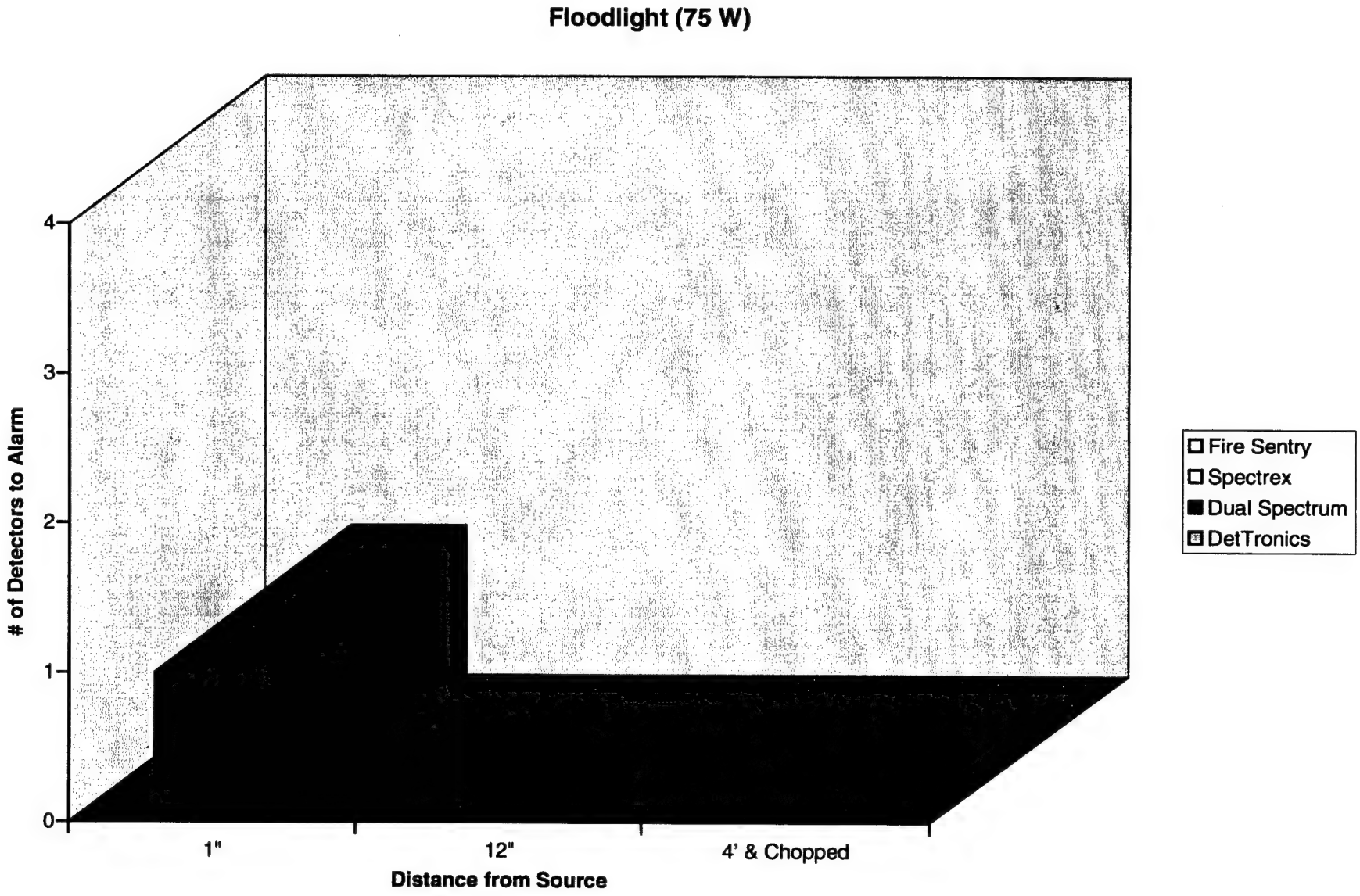
Graph 26


Incandescent Light (75 W, soft white)
# of Detectors to Alarm
0
1
2
3
4
1"
6"
12"
24"
4' & Chopped
Distance from Source
Fire Sentry
Spectrex
Dual Spectrum
DetTronics

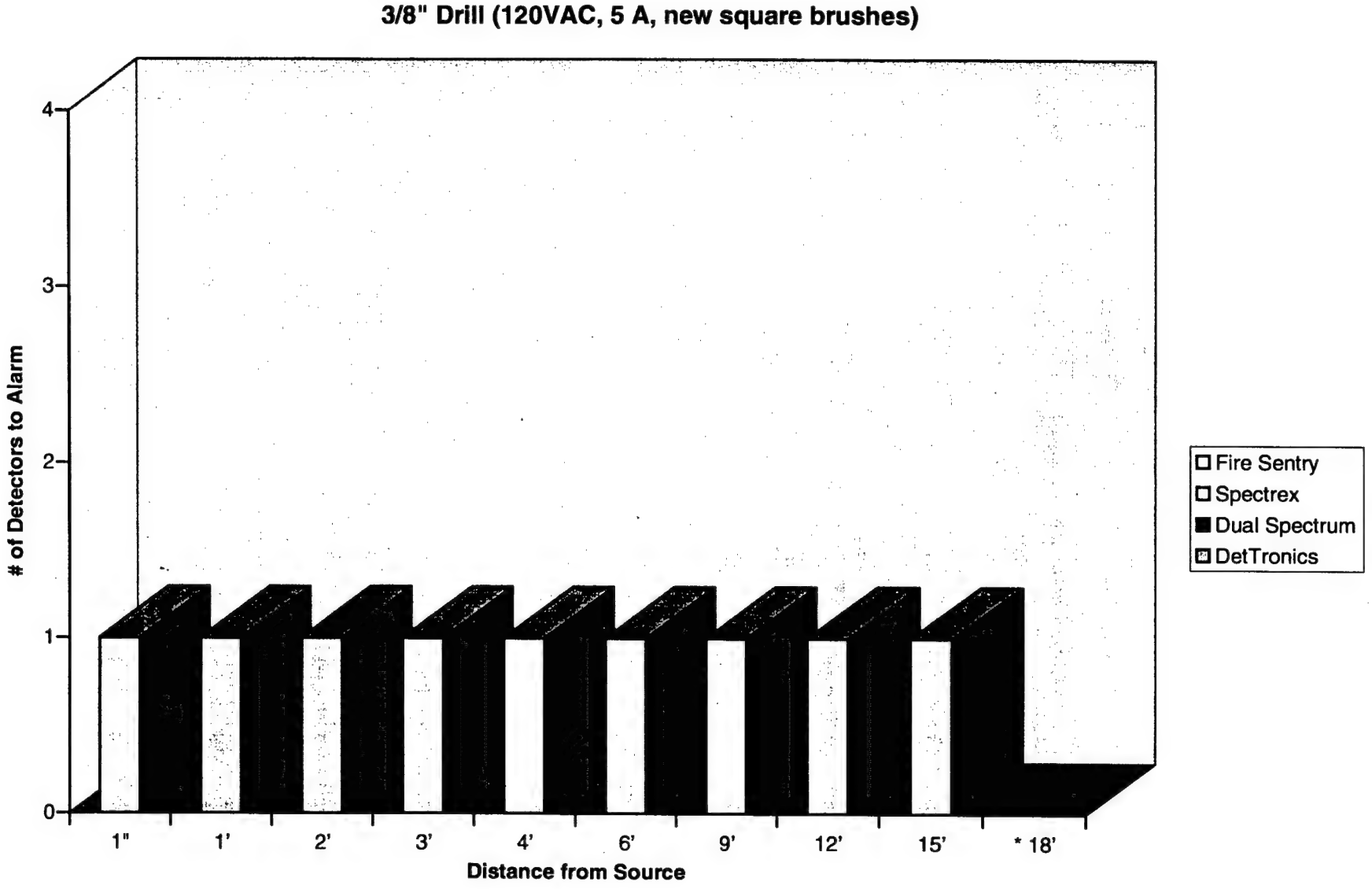
Graph 27


Phillips EarthLight (17 W, fluorescent)
# of Detectors to Alarm
0
1
2
3
4
1"
6"
4' & Chopped
Distance from Source
Fire Sentry
Spectrex
Dual Spectrum
DetTronics

Graph 28

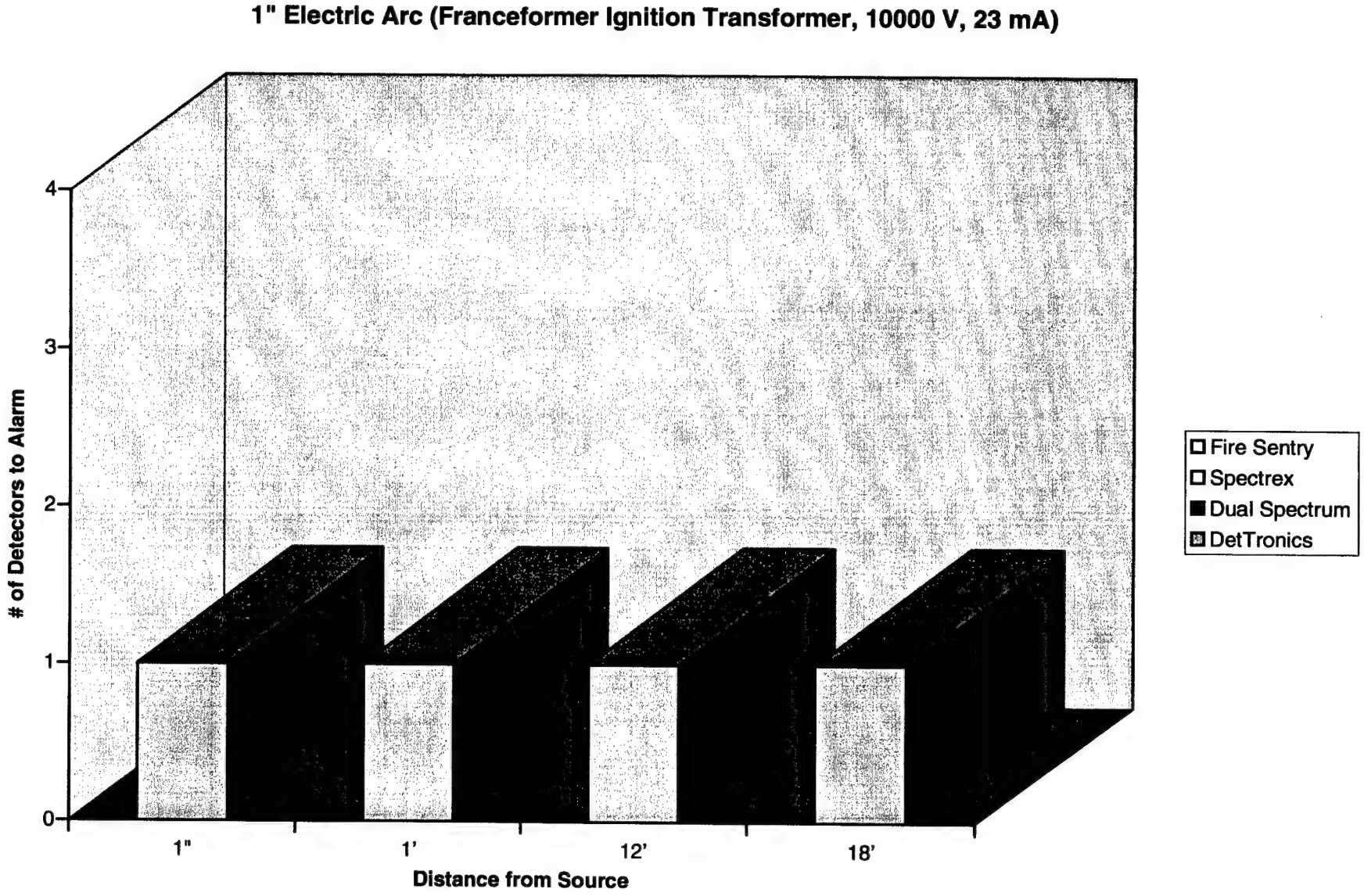

Floodlight (75 W)
# of Detectors to Alarm
0
1
2
3
4
1"
12"
4' & Chopped
Distance from Source
Fire Sentry
Spectrex
Dual Spectrum
DetTronics

Graph 29

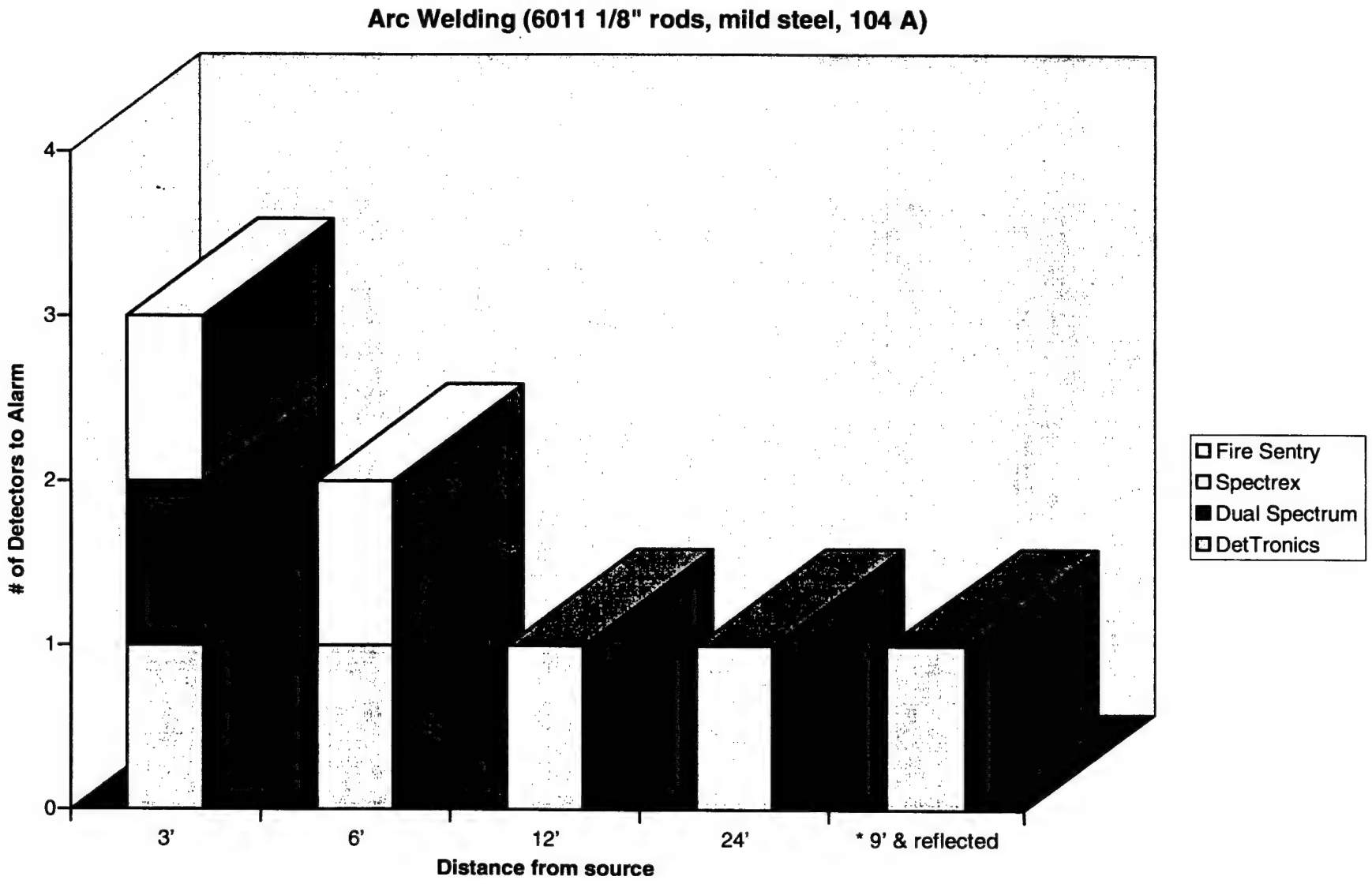


*** Detector did not alarm at 18 feet and beyond**

Graph 30


1" Electric Arc (Franceformer Ignition Transformer, 10000 V, 23 mA)
# of Detectors to Alarm
0
1
2
3
4
1"
1'
12'
18'
Distance from Source
Fire Sentry
Spectrex
Dual Spectrum
DetTronics

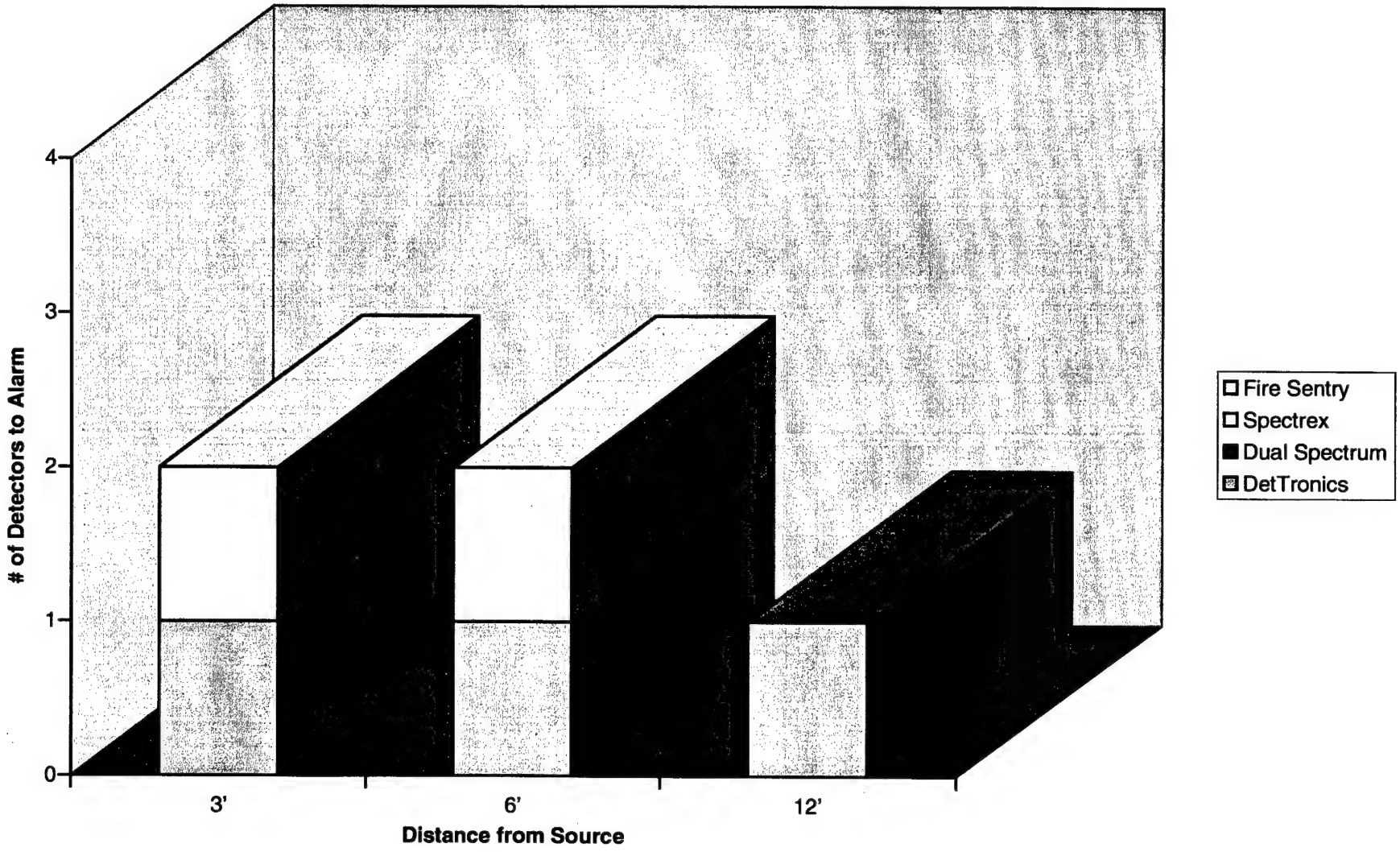
Graph 31



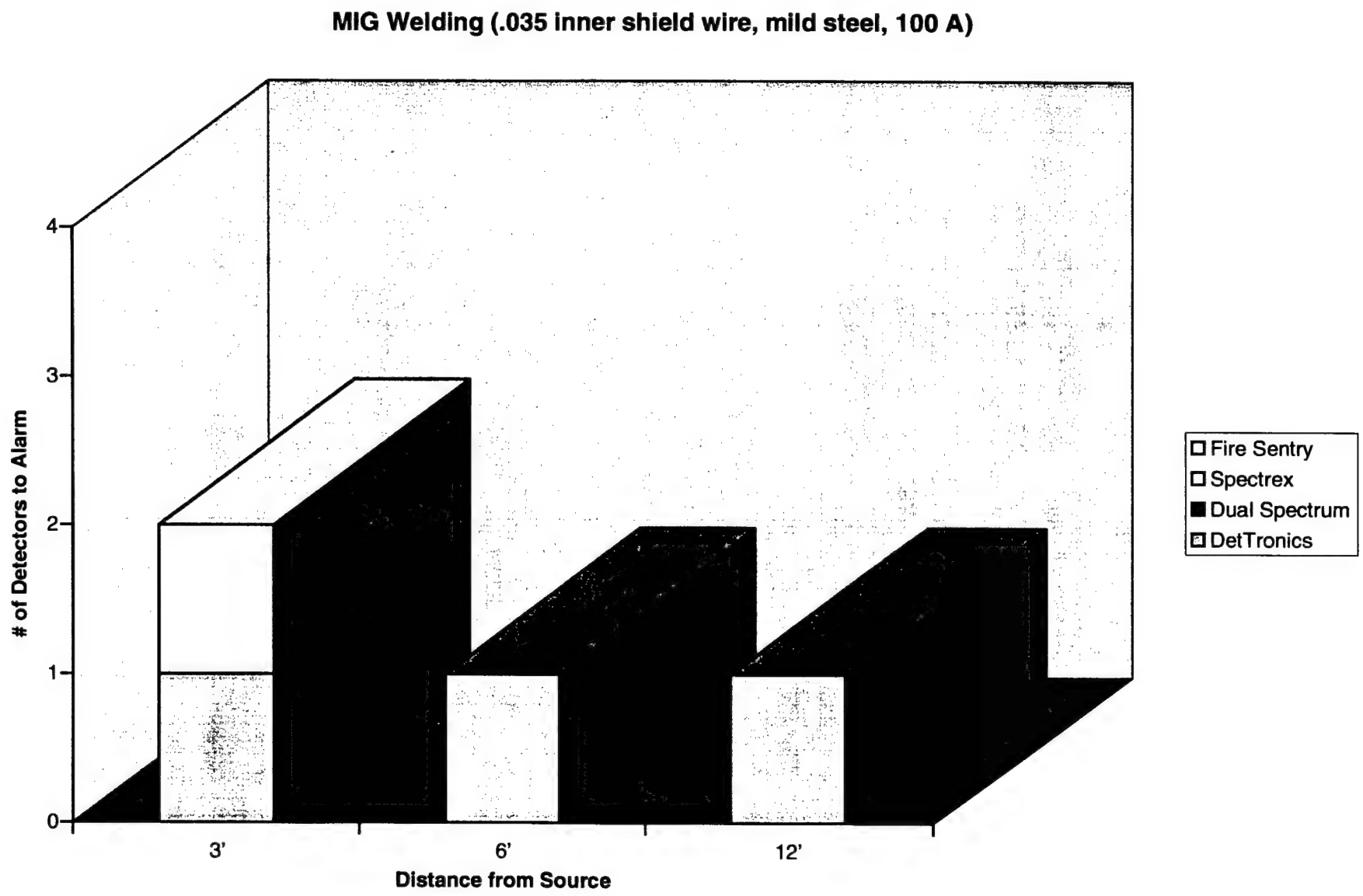
*** The welding source was reflected off of a smooth painted wall**

Graph 32

Arc Welding (Palco 680 1/8" rods, Al Alloy, 104 A)

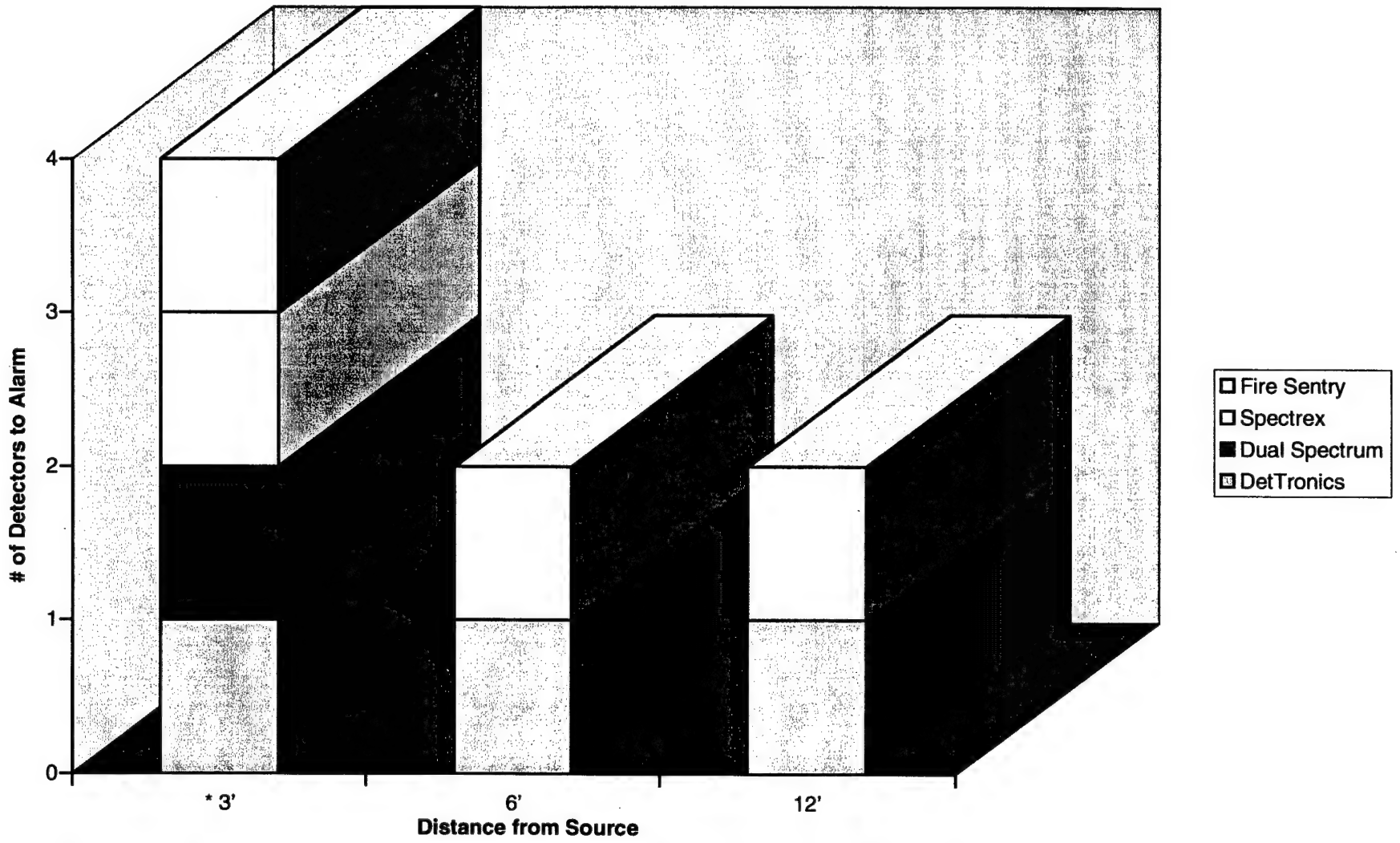


Graph 33


MIG Welding (.035 inner shield wire, mild steel, 100 A)
# of Detectors to Alarm
0
1
2
3
4
3'
6'
12'
Distance from Source
Fire Sentry
Spectrex
Dual Spectrum
DetTronics

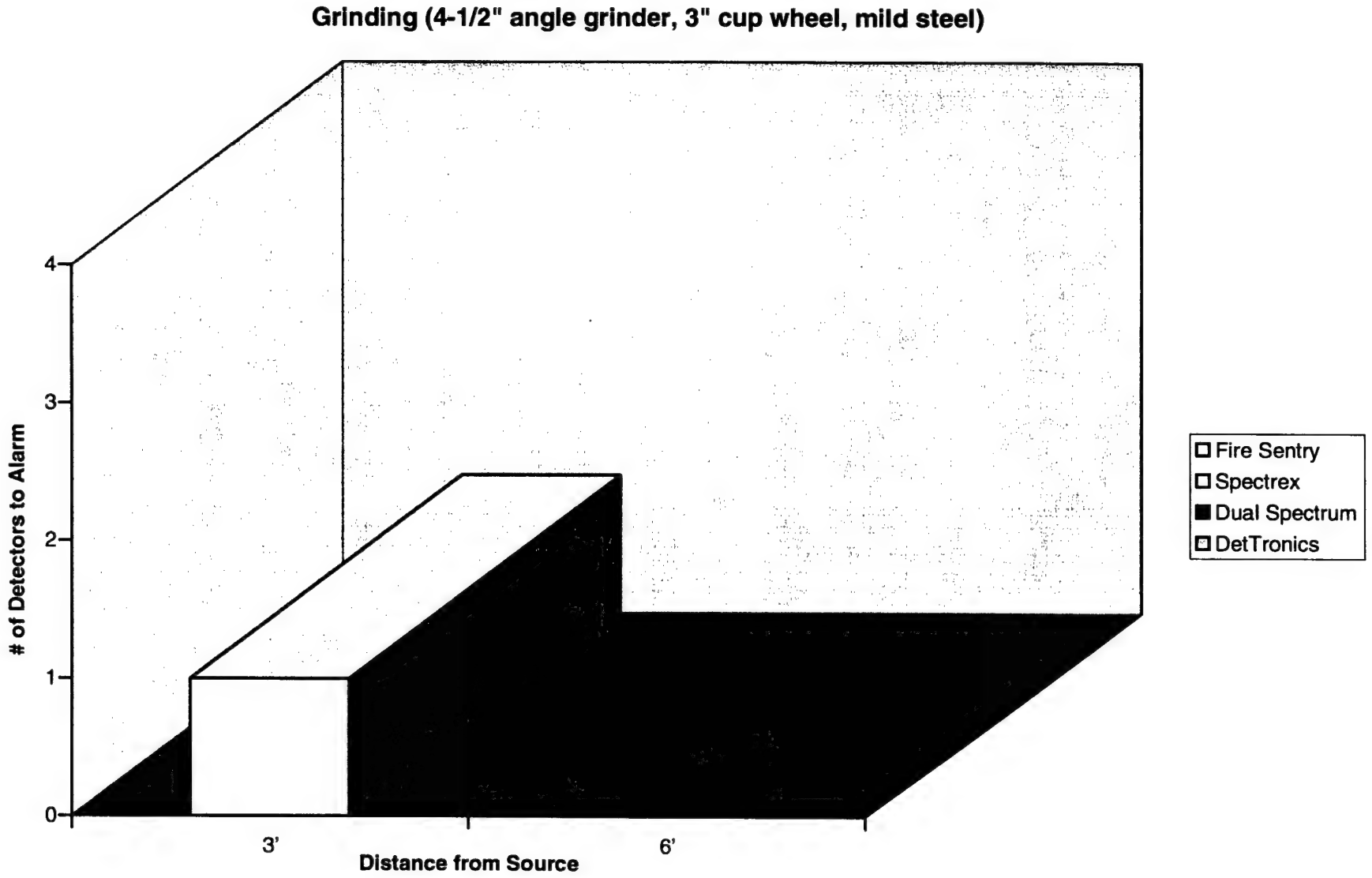
Graph 34

Acetylene Torch (lighting and cutting 3/8" mild steel)



*** This is the only false alarm stimuli test that activated the Spectrex detector at any distance**

Graph 35


Grinding (4-1/2" angle grinder, 3" cup wheel, mild steel)
# of Detectors to Alarm
0
1
2
3
4
3'
6'
Distance from Source
Fire Sentry
Spectrex
Dual Spectrum
DetTronics

Graph 36

APPENDIX 3

SUMMARY OF EACH TEST CONDUCTED AS PART OF PHASE I EFFORT

29 Jan 96
1330 HRS Event #1

Green Smoke 1/2lb (Det Tronics detector in use Model #C7050), with the 4303 Det Tronics Controller and detector. Test performed by Tom Moore using 16 gauge 18 inches x 18 inches x 2 inches metal pan centered directly below the sphere. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Initiation was accomplished by electric match with smokeless gunpowder as starter. As mixture was initiated a plume of green smoke approximately 6 inches high rose from the mixture followed by small flame (approximately 5 inches in diameter). Additional information:

Det event to sphere water - 33ms
Det event to sphere water on flame - 45ms
Det event to H_2O on table - 48ms
Det event to follow-on water - 66ms
Det event to suppression - 52ms

Fire was extinguished before follow-on water reached the flame. Note: Unburned residue was observed on lexan shield, floor and captured on water filter installed in the environmentally approved drainage system outside the test room.

30 JAN 96
1330 HRS Event #1

Yellow smoke 1/2lb (Det Tronics detector Model #C7050), with 4303 Det Tronics controller and detector. Tom Moore using 16 gauge 18 inches x 18 inches x 2 inches metal pan centered directly below the sphere. A 10 liter sphere with 22 lbs. of water was used. Initiation of the material burn was done with an electric match and smokeless gunpowder as starter. As mixture was initiated a plume of yellow smoke approximately 4 inches high followed by flame (approximately 3 inches wide and 5 inches high) was observed. Additional information:

Det event to sphere water - 21ms
Det event to sphere water on flame - 34ms
Det event to water on table - 39ms
Det event to follow-on water - 53ms
Det event to suppression - 47ms

Fire was extinguished before follow-on water reached the flame. Note: Unburned residue was present on table, lexan shield, and in the water filter, indicating that the ultra high speed detection/suppression system was stopping the "burn" before total burn out. Over pressure measured separately at the event was ½ psi.

30 JAN 96
1500 HRS Event #2

MK-18 project load, Illuminating compound 1/2lb. Spectrex detector with controller modified on site before the test. Tom Moore performed the test with a 16 gauge 18 inches x 18 inches x 2 inches metal pan centered directly below the sphere. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Initiation was done with an electric match and smokeless gunpowder as starter. As mixture was initiated smoke and sparks rose approximately 9 inches above the table followed by 10 inches narrow flame. Additional information:

Det event to sphere water - 54ms *see note
Det event to water on flame - 64ms
Det event to water on table - 72ms
Det event to suppression - 77ms

In this event the follow-on water did not respond. This was because the modified controller did not close the relay to provide 120 volts to the solenoid valves. In addition, the high speed camera indicated a fairly large ball of fire (approximately 3 inches in diameter) was not detected. *Note: The undetected flame ball if identified as a detectable event would have increased the water at sphere time to 198 ms. There was a large amount of unburned residue in the deflagration as well as burning/sparking material. A lot of unburned residue was left in the filter, on the table and on the floor. Controller was modified on-site by SPECTREX factory technician, Mr. Nive. Copious amounts of smoke were visible after the test.

31 JAN 1996
0915 HRS Event #1

Yellow smoke mix 1/2lb using SPECTREX detector with site modified (2nd time) controller. Tom Moore performed the test with a 16 gauge 18 inches x 18 inches x 2 inches metal pan centered directly below the sphere. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Initiation was accomplished with an electric match and smokeless gunpowder as starter. As mixture was initiated smoke rose approximately 17 inches followed by narrow fast moving flame. Flame rose to about 15 inches before being intercepted by water from the sphere. Additional information:

Det event to sphere water - 51ms

Det event to water on flame - 64ms
Det event to water on table - 75ms
Det event to suppression - 85ms
Det reaction to follow-on water - 108ms

Unburned residue on table, lexan shield and in filler. Note: The event as seen on the high speed camera indicated two detectable flames. The undetected flame occurred approximately 10ms before the second fire.

31 JAN 96
1230 HRS Event #2

Red lead delay composition for MK 875, 1/2lb, using Det Tronics detector Model #C7050 with 4303 Det Tronics controller. Test performed by Mike Purcell with 16 gauge, 18 inches x 18 inches x 2 inches metal pan centered directly below the sphere. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Initiation was done with an electric match and smokeless gunpowder as starter. Extremely fast moving flame (very bright) with no smoke visible. Flame propagated to sphere top and was approximately 3 feet in diameter. Additional information:

Det event to sphere water - 13ms (est)
Det event to water on flame - 13ms (est)
Det event to water on table - 31ms
Det event to follow-on water - 39ms
Det event to suppression - 117ms

This was a very energetic reaction. The flame was very bright and difficult to see on the high speed camera. Unburned residue could be observed in the high speed video, was visible on the floor and present in the water filter indicating that the fire was extinguished before it burned out.

31 JAN 96
1500 HRS Event #3

Red lead composition for MK 875, 1/4lb (note change in amount of material. Previous test amount was too strong/energetic. Did not want to damage detectors). Detector used was SPECTREX. Mike Purcell was tester using same metal pan with material situated directly under its 10 liter sphere (500 psi nitrogen pressure with 22 gal. of water). Electric match and gunpowder (smokeless) were used to initiate the mixture. Extremely fast moving flame with very bright reaction. Flame rose to approximately the height of sphere (36 inches).

Det event to sphere water - 15ms

Det event to water on flame - 15ms
Det event to water on table - 35ms
Det event to follow-on water - 50ms
Det event to total suppression - 115ms

Unburned red lead material was visible on the table, on the floor and in the filter. Although water was on the burning material the material continued to burn for approximately 100ms before it was completely extinguished.

1 FEB 96
0900 HRS Event #1

Red lead composition for MK 875, 1/4lb. Det Tronics detector using detector Model #C7050 with 4303 Det Tronics controller. Test performed by Mike Purcell. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. New stainless steel pan (20 gauge) installed. Initiation was accomplished using an electric match and smokeless gunpowder. Extremely bright flash with flame projecting above the sphere. Residue (unburned) was observed on the table, floor and filter and was visible in the high speed video picture. Additional information:

Det event to sphere water - 19ms
Det event to water on flame - 19ms
Det event to water on table - 37ms
Det event to follow-on water - 59ms
Det event to total suppression - 119ms

Note: This energetic material continued to burn for a period even after the sphere water and follow-on water were on the material. However, the fire was well under control and the sphere water (approximately 500ms in total duration) was more than sufficient in quantity and duration to provide complete extinguishment.

1 FEB 96
1100 HRS Event #2

Red lead composition for the MK875, 1/4lb. Det Tronics detector Model #C7050 with 4303 Det Tronics controller. Test performed by Mike Purcell. Note: Mr. Vickers came to site and requested a test without use of the sphere. He was concerned that the material was burning itself out before activation of the sphere and extinguishment. The test was conducted using follow-on water only with a digital timer placed in left nozzle. Big blast. All residue burned. The entire table area was saturated with flame (totally engulfed). One nozzle activated at 41ms but had no effect on the fire. There was smoke throughout the room for approximately 20 minutes with burnt material residue on the

sphere, nozzles, detectors, lexan screen and VHS camera monitor some 15 feet away. Bottom line, sphere is extinguishing the fires.

1 FEB 96
1400 HRS Event #3

Red lead composition for the MK875, 1/4lb of material using the Dual Spectrum Santa Barbara detector. Mike Purcell performed the test with a 20 gauge stainless steel 18 inches x 18 inches x 2 inches pan. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished using an electric match and a small amount of smokeless gunpowder. An extremely bright flash with virtually no smoke was observed on the high speed camera. The flame only rose 12 inches and was considerably smaller than previously observed with the red lead mixture. Measured times were as follows:

Det event to sphere water - 15ms
Det event to water on flame - 25ms
Det event to water on table - 35ms
Det event to follow-on water - could not be determined because it could not be seen on the camera. The sphere had put the fire out.
Det event to total suppression - 55ms

1 FEB 96
1400 HRS Event #4

Yellow smoke composition 1/2lb using the Dual Spectrum Santa Barbara detector. Mike Purcell was to perform the test using the same set up as described in event #3. However, there were problems in the pre-operational procedures. Materials are not placed on the table in this procedure. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. As the checklist was being accomplished the sphere fired. As a result the test must be re-accomplished. The rest of the day was used to check the system to include detectors, control panels and associated wiring. A reason for the activation could not be determined. The Dual Spectrum engineer and technician was on-site at the time and assisted in system check-out.

2 FEB 96
0900 HRS Event #1

M125 Illuminate composition 1/4lb with Dual Spectrum Detector. As the power up procedures were being accomplished another false alarm occurred. The cause of the false alarm could not be determined but was generally associated with the Fenwal panel.

Since much effort would by required to completely determine the problem it was decided to switch to an available controller (RAM/LAM) that was compatible with all the detectors being tested. This was done and the problem was eliminated.

2 FEB 96
1340 HRS Event #2

Note: This is the first test accomplished after set up of the Pyrotech International Ram/Lam Controller. By using this system the problems associated with using a different controller were eliminated. The processing time of this unit is approximately one (1) millisecond or less.

M125 Illuminate composition, 1/4lb of material using the Det Tronics detector. Tom Moore performed the test with a 20 gauge steel, 8 inches x 18 inches x 2 inches pan. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished using an electric match and a small amount of smokeless gunpowder. The flame produced by the ignition was approximately 6 inches high by approximately 3 inches wide. No smoke was visible. The camera aperture was set higher to assure a dark background on the high speed camera. Residue from the explosion was visible with the high speed camera, also on the table, floor and in the filter system. Measured times were as follows:

Det event to sphere water - 33ms
Det event to water on flame - 43ms
Det event to water on table - 48ms
Det event to extinguishment of flame - 52ms

*Note: The flame was extinguished quickly but the follow-on water could not be observed with high speed photography. Also, no tests were done on 5 Feb 96 due to a hard freeze. Testing was re-started on 6 Feb 96.

6 FEB 96
0900 HRS Event #1

Starter composition for the MK25 marine locate marker, 1/4lb with Dual Spectrum Santa Barbara detectors. Tom Moore performed this test with a 20 gauge 18 inches x 18 inches x 2 inches, steel pan. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished using an electric match and a small amount of smokeless gunpowder. There was a delay before the material burned. We basically observed the same type action with the 125 mix. It was determined that it was the mix and not the powder that was burning. This burn resulted in a large smoke plume with sparks approximately 18 inches tall by 6 inches wide. Maximum flame size was

approximately 5 inches tall by 2 inches wide when extinguished. Measured times were as follows:

Det event to sphere water - 50ms
Det event to water on flame - 60ms
Det event to water on table - 67ms
Det event to follow-on water - 92ms
Det event to extinguishment of flame - 72ms

6 FEB 96
1120 HRS Event #2

Yellow Smoke composition, 1/2lb with the Dual Spectrum Santa Barbara detector. Tom Moore performed this test with an 18 inches x 18 inches x 2 inches, 20 gauge steel pan. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished by an electric match and smokeless gunpowder. A yellow smoke plume rose quickly to the bottom of the sphere followed by extinguishment with the sphere and follow-on water. At this point in the test the tape was eaten by the high speed camera/processor. Subsequent telephone conversations with the factory technicians suggested adjustments and cleaning of the unit. This was done and the problem disappeared. Because of the loss of high speed tape, the data for this test was not available. Test will be re-accomplished.

6 FEB 96
1325 HRS Event #3

Starter composition for the MK25 marine locate marker, 1/4lb with Det Tronics detector, Model #4303. Tom Moore performed the test placing the mixture in an 18 inches x 18 inches x 2 inches, 20 gauge steel pan. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition as accomplished using an electric match and smokeless gunpowder. As the mixture ignited it burned for approximately 0.5 seconds before detected by the detector. The mixture sparked before ignition. The measured times were as follows:

Det event to sphere water - 26ms
Det event to water on flame - 36ms
Det event to water on table - 40ms
Det event to follow-on water - 161ms
Det event to fire extinguishment - 43ms

6 FEB 96
1500 HRS Event #4

Starter composition for the MK25 marine locate marker, 1/4lb SPECTREX. Tom Moore performed the test using the same procedures in event #3. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished using an electric match and smokeless gunpowder. The measured times were as follows:

Det event to sphere water - 24ms
Det event to water on flame - 36ms
Det event to water on table - 42ms
Det event to follow-on water - 77ms
Det event to fire extinguishment - 46ms

Note: Prior to detection of the event in this test a fire of approximately 4 inches x 8 inches occurred early in the burn. This event was not detected by the Spectrex detector however. There was very little smoke as the fire drifted up and closer to the detectors. This small fire existed for approximately 200ms before being engulfed by the second flame that was detected.

7 FEB 96
0900 HRS Event #1

M206 IR flare composition. The first test was from a pan with 1/4lb of this mixture without the sphere or follow-on water to "feel out" the energy associated with this volatile Pyrotechnic mix. The material burned with a loud "bang" that sounded like a small detonation. The smoke and fire rose to over 6 feet and singe marks were left where the pan was sitting. The material would be halved to approximately 1/8lb or 50 grams, in future tests. The material burned extremely hot and bright. All the material was completely consumed with no evidence of unburned residue.

7 FEB 96
1030 HRS Event #2

M206 IR flare composition 1/8lb with the Det Tronics detector. Tom Moore performed the test using the 18 inches x 18 inches x 2 inches 20 gauge steel pan. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished with an electric match and smokeless gunpowder. There was a very fast energetic reaction with the fire being quickly extinguished by the sphere. The measured times were as follows:

Det event to sphere water - 12ms
Det event to water on flame - 12ms
Det event to water on table - 41ms

As a best visual estimate. It is believed that the extreme heat of the burn actually evaporated the leading edge of the water plume before it reached the table.

Det event to follow-on water - 133ms
Det event to fire extinguishment - 75ms

The event, for some reason was erased from both the VHS and high speed cameras. The event times above were taken immediately after the test.

7 FEB 96
1100 HRS Event #3

M206 IR flare composition 1/8lb (approximately 50 g) with the Dual Spectrum Santa Barbara detector. Tom Moore performed the test using an 18 inches x 18 inches x 2 inches, 20 gauge pan to contain the material. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished with an electric match and smokeless gunpowder. There was a very fast energetic reaction that was easy to see and define. Flame was approximately 3 feet in diameter and propagated up to the sphere. The flame was quickly extinguished by the sphere and was not noticeable to the naked eye from the VHS real time video. It could be clearly seen on the high speed camera. The data recordings are as follows:

Det event to sphere water - 7ms
Det event to sphere water on fire - 7ms
Det event to water on table - 28ms
Det event to follow-on water - Was unable to determine. Note aperture was adjusted to a higher reading (3.5) to observe the definition and shape of the flame. Because the background was so dark the follow-on water could not be observed.
Det event to fire extinguishment - 53ms

7 FEB 96
1320 HRS Event #4

M206 IR flare composition 50 grams with the Spectrex detector. Mike Purcell performed the test using an 18 inches x 18 inches x 2 inches, 20 gauge steel pan to contain the material. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished with an electric match and smokeless gunpowder.

Very fast energetic reaction as was with the previous burns involving this mix. The data recordings were as follows:

Det event to sphere water - 6ms
Det event to sphere water on fire - 6ms
Det event to water on table - 22ms Observed from splashing residue on table
Det event to follow-on water - 46ms
Det event to fire extinguishment - 66ms

7 FEB 96
1520 HRS Event #5

M206 IR flare composition 50 grams with the Fire Sentry detector. Mike Purcell performed the test using an 18 inches x 18 inches x 2 inches 20 gauge pan to contain the material. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished with an electric match and smokeless gunpowder. Very fast energetic reaction as was observed with previous burns of 206 mixture. The data recordings were as follows:

Det event to sphere water - 7ms
Det event to sphere water on fire - 7ms
Det event to water on table - 22ms
Det event to follow-on water - 118ms
Det event to fire extinguishment - 63ms

8 FEB 96
0900 HRS Event #1

1/2lb Green smoke with Det Tronics detector and RAM/LAM controller. While connecting the squib the sphere discharged. The controller was on and in the by-pass position. As a result of this occurrence, testing was terminated and a complete checklist review was done. Among changes made with the checklists the following additions were made.

a. Completely powered down the RAM/LAM controller while attaching the sphere. Apparently an electrical component in the controller shorted out and gave full capacity out-put to activate the sphere.
b. Shunt sphere wires to prevent static discharge.
c. Check voltage across sphere wires prior to powering down.

Since re-accomplishment of the checklist and a positive two-man cross check of each event, no other problems have been observed with system operation.

12 FEB 96
1250 HRS Event #1

Green smoke 1/4lb using the Fire Sentry detector. Mike Purcell performed the test using an 18 inches x18 inches x 2 inches, 20 gauge stainless steel pan to contain the material. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished with an electric match and smokeless gunpowder. A column of thick dark green smoke rose quickly up to a height to about the bottom of the sphere. From a visual observation it appeared that four or five seconds elapsed before water was observed on the "burn". A flame of about 6 inches high and 3 inches wide was observed just before the sphere discharged water. No smoke was observed after sphere discharge. Residue (unburned) was observed on the floor, table and in the water filter. Data recorded was as follows:

Det event to sphere water - 50ms
Det event to sphere water on fire - 64ms
Det event to sphere water on table - 67ms
Det event to follow-on water - 101ms
Det event to fire extinguishment - 72ms

12 FEB 96
1500 HRS Event #2

Green smoke 1/4lb using the Fire Sentry detector and RAM/LAM controller. Mike Purcell performed the test using an 18 inches x 18 inches x 2 inches 20 gauge steel pan to contain the material. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished with an electric match and smokeless gunpowder. The reaction for event #2 was about the same as for event #1 except a small flame was visible to the eye this time. From a visual observation it appeared that approximately four seconds elapsed before water hit the fire. The smoke rose about 18 inches. Three small fire balls were observed on the high speed camera before the detectable event occurred. Fire grew to about 6 inches x 3 inches before activation of the sphere. Data recorded was as follows:

Det event to sphere water - 45ms
Det event to sphere water on fire - 61ms
Det event to sphere water on table - 63ms
Det event to follow-on water - 155ms
Det event to fire extinguishment - 68ms

13 FEB 96
0930 HRS Event #1

MK-18 Illuminate composition for the signal illuminating ground star cluster, 1/4lb Fire Sentry detector. The RAM/LAM controller was used. Mike Purcell performed the test using an 18 inches x 18 inches x 2 inches 20 gauge steel pan to contain the material. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished with an electric match and smokeless gunpowder. Starting with this test the assistant project officer will announce "material" and "detector" being used right before each test. The mixture used was hard and lumpy and had to be broken up before ignition. As the mixture burned a small amount of smoke was visible. No further burning occurred and a misfire was declared. The material was too hard to burn.

13 FEB 96
1020 HRS Event #2

This event essentially was a repeat of event #1 which was declared a misfire. This time however, the MK-18 Illuminate composition burned and was detected by the Fire Sentry detector. The maximum fire ball size observed in this test was about 10 inches diameter. After the detector fired lots of debris was observed on the table and floor. Data recorded was as follows:

Det event to sphere water - 35ms
Det event to water on flame - 46ms
Det event to water on table - 50ms
Det event to follow-on water - 151ms
Det event to fire extinguishment - 116ms

13 FEB 96
1245 HRS Event #3

MK-18 Illuminate compound 1/4lb using the Dual Spectrum Santa Barbara detector. Mike Purcell performed the test using an 18 inches x 18 inches x 2 inches 20 gauge steel pan to contain the material. Ignition was accomplished using the electric match and smokeless gunpowder. A small amount of smoke was observed and a small ball of flame (2 inches or so) was visible to the eye. The high speed camera displayed a maximum fire size of 8 inches. Data recorded was as follows:

Det event to sphere water - 49ms
Det event to water on flame - 63ms
Det event to water on table - 66ms
Det event to follow-on water - 146ms
Det event to fire extinguishment - 73 ms

14 FEB 96

1140 HRS Event #1

Red Lead 1/4lb using the Dual Spectrum Santa Barbara detector and Pyrotech International RAM/LAM controller. Mike Purcell performed the test using an 18 inches x 18 inches x 2 inches, 20 gauge pan to contain the material. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished with an electric match and smokeless gun powder. There was a characteristic highly energetic reaction which was not obvious without the high speed camera. The high speed camera revealed a flame approximately 2 1/2 to 3 feet diameter. Data recorded was as follows:

Det event to sphere water - 10 ms
Det event to water on flame - 14 ms
*Det event to water on table - 31 ms
**Det event to suppression - 133 ms

*As with the other bright fires it appears some of the water is evaporated by an intense heat prior to reaching the table or cannot be seen until the fire starts to cool down.
** This again is total suppression. The fire ball is well under control several milliseconds prior to total suppression (in this case contained in approximately 28 ms).

Temp - 67°F
Barometric Pressure - 29.92 in hg
Humidity - 59%

14 FEB 96
1315 HRS Event #2

Red lead 1/4 lb using the Fire Sentry detector and the Pyrotechnic International controller. Mike Purcell performed the test using the same equipment as described in Event #1. The sphere was not used in this test to evaluate the systems reaction with follow-on water only. Ignition was accomplished with an electric match and smokeless gunpowder. Data recorded was as follows:

The intense reaction was so energetic and bright that the high speed camera was completed saturated. The follow-on water activation could not be observed on the camera because of the brightness. The reaction produced a loud deflagration, lots of smoke and no observable unburned residue. The follow-on water however, was observed when reaction lessened in intensity but no time was recorded for activation.

Temp - 69°F
Barometric Pressure - 29.90 in hg
Humidity - 59%

14 FEB 96

1415 HRS Event #3

Red lead 1/4lb with the Fire Sentry detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test using the 18 inches x 18 inches x 2 inches, 20 gauge pan, an electric match and smokeless gunpowder. There was a very fast, easily defined reaction. Unburned residue was visible on the table and floor. Data recorded was as follows:

Det event to sphere water - 7 ms
Det event to water on flame - 10 ms
*Det event to water on table - 39 ms
*Det event to follow-on water - 88 ms (hard to see)
*Det event to total suppression - 59 ms (hard to see)

The fire was contained in 35 ms. This is the time when it can be clearly determined from the camera that the fire was getting smaller.

Temp - 69°F
Barometric Pressure - 29.88 in hg
Humidity - 61%

16 FEB 96
0945 HRS Event #1

Green smoke 1/4lb using the Dual Spectrum Santa Barbara detectors and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test using the 18 inches x 18 inches x 2 inches, 20 gauge pan, an electric match for ignition and smokeless gunpowder. The material generated smoke, flame and sparks as it ignited. The smoke column was approximately 5 inches wide by 9 inches tall, with a small flame visible to the naked eye. Data recorded was as follows:

Det event to sphere water - 73 ms
Det event to water on flame - 87 ms
Det event to water on table - 90 ms
Det event to follow-on water - 166 ms
Det event to total suppression - 96 ms

Note: Unburned residue was observed on the table and floor and the sphere put out the fire prior to follow water activation.

Temp - 72°F
Barometric Pressure - 29.98 in hg
Humidity - 29%

16 FEB 96
1040 HRS Event #2

Type 1 First Fire mix, 1/4lb using the Dual Spectrum Santa Barbara detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the tests using the same pan as described in event #1, an electric match and smokeless gunpowder. A small flame approximately 6 inches wide by 4 inches tall was observable to the naked eye. Data recorded was as follows:

Det event to sphere water - 58 ms
Det event to water on flame - 73 ms
Det event to water on table - 75 ms
Det event to follow-on water - 144 ms
Det event to total suppression - 82 ms

Note: Observation of the high speed camera revealed an unclear detectable event. The observation was not easy to define. The flame started with small localized fires (2 or 3) that finally merged together. When the small fires merged together a detectable event time was established. There was unburned residue on the table and floor.

Temp - 73°F
Barometric Pressure - 29.99 in hg
Humidity - 29%

16 FEB 96
1300 HRS Event #3

Type 1 First Fire mix, 1/4lb using the Spectrex detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the tests using the pan described in tests #1 and #2, an electric match and smokeless gunpowder. A flame approximately 6 inches wide by 7 inches tall was observed on the high speed camera and could be seen by the naked eye. Residue was visible on the table an the floor. Data recorded was as follows:

Det event to sphere water - 290 ms
Det event to water on flame - 305 ms
Det event to water on table - 308 ms
Det event to follow-on water - 373 ms
Det event to total suppression - 322 ms

Note: This was a relatively slow developing event compared with event #2. The detectable event to sphere water comparison to the previous event to sphere water comparison to the previous test was 232 ms longer. However it should be noted that it took approximately 135 ms longer for this fire to grow to 4 inches tall.

Temp - 74°F
Barometric pressure - 29.97 in hg
Humidity - 25%

16 FEB 96
1349 HRS Event #4

Green Smoke, 1/4lb using the Spectrex detector and Pyrotech International RAM/LAM controller. Mike Purcell performed the test using the pan described in test #1. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Ignition was accomplished with an electric match and smokeless gunpowder. There was a small fire (probably the match) followed by a tall (20 inches) column of green smoke. The high speed camera revealed sparkling and smoke before a clearly definable flame was apparent. Max smoke size was about 8 inches x 20 inches. Max flame size was approximately 6 inches wide by 14 inches tall. There was unburned residue on the test table and floor. Data recorded was as follows:

Det event to sphere water - 108 ms
Det event to water on flame - 120 ms
Det event to water on table - 124 ms
Det event to follow-on water - 196 ms
Det event to total suppression - 130 ms
Temp - 74°F
Barometric Pressure - 29.97 in hg
Humidity -

20 FEB 96
1021 HRS Event #1

M125 Illuminate Composition, 1/4lb using the Spectrex detector with RAM/LAM controller. Mike Purcell performed the test using an 18 inches x 18 inches x 2 inches, 20 gauge pan to contain the material. Ignition was accomplished with an electric match and smokeless gunpowder. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Noting from past experiments that the same material may exhibit different propagation rates, all detectors from this experiment forward will be looking at the same event for detection reaction time comparisons. However, only one detector will be configured to activate the suppression system for the given event. In this test it will be the Spectrex unit. In this event there was a small amount of smoke with a flame size of approximately 4 inches wide x 9 inches tall. There was unburned residue on the test table and floor. Data recorded was as follows:

Det event to sphere water - 60 ms
Det event to water on flame - 75 ms
Det event to water on table - 76 ms
Det event to follow-on water - 99 ms
Det event to total suppression - 81 ms

Detection reaction times are as follows:

(1) Fire Sentry - 31 ms

(2) Dual Spectrum Santa Barbara - 38 ms
(3) Det Tronics - 39 ms
Spectrex - 58 ms

20 FEB 96
1235 HRS Event #2

M125 Illuminate Composition, 1/4lb using the Det Tronics detector. Mike Purcell performed the test with the same procedures and equipment listed for event #1. Data was lost due to problems with the high speed camera. When the second button was pressed the tape ejected. This was the first of approximately eight (8) events where malfunction of the camera occurred. These events happened intermittently (not consecutive). In an attempt to correct these problems over the 8 event period, the following actions were taken:

(1) Cleaned tape heads and demagnetized the heads.
(2) Cleaned rollers.
(3) Called manufacturer and was unable to resolve the problem over the phone. The company had not experienced these problems before.
(4) Removed peripheral electrical devices to limit power requirements to vital test equipment.
(5) Repositioned camera to reduce suspected vibration due to explosion generated short.
(6) Isolated incoming power source to camera. Isolated the controller (RAM/LAM) from the electronic data interface (EDI) box of the high speed camera. After completing this step the problem has not re-occurred.

Note: While experiencing these problems it was noted after the third test that the high speed camera functioned normally up to the time the sphere fired. Partial data was then collected for the next five events of the total of eight malfunctioning tests.

20 FEB 96
1315 HRS Event #3

M125 Illuminate Composition, 1/4lb using the Det Tronics detector. The test could not be completed because of problems that occurred with the RAM/LAM controller. This occurred as the checklist was being implemented. The controller was sent back to the manufacturer who replaced the primary electronic power switches with similar components. As problems subsequently continued to occur the problem switches were eventually replaced with bigger units on 26 March. These replacement electronic power switches are designed to fire squibs and or solenoid valves. The original ones only fired solenoid valves. This changeover appears to have solved the problem.

28 FEB 96
0915 HRS Event #1

Red lead, 1/4lb using the Spectrex detector. No data was recorded because of tape ejection.

28 FEB 96
1015 HRS Event #2

Red lead, 1/4lb using the Spectrex detector. No data was recorded because of tape ejection. However, at this time it was realized that some data (partial) could be retrieved which was done in the following events where the camera malfunctioned.

28 FEB 96
1100 HRS Event #3

Red lead, 1/4lb using the Spectrex detector, with RAM/LAM controller. Tom Moore performed the test using an 18 inches X 18 inches X 20 gauge pan to contain the material. Ignition was accomplished with an electric match and smokeless gunpowder. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Characteristically there was a fast energetic reaction. Unburned residue was present on table and floor. The camera again malfunctioned, however the following data was retrieved:

Det event to sphere water - 6 ms

* Det reaction time:

Spectrex - 6 ms

* The event was not seen by the other detectors up to the 6ms time-frame. After the 6ms event the camera malfunctioned, therefore a determination of the remaining detectors speed for detection could not be observed.

28 FEB 96
1350 HRS Event #4

Red lead, 1/4lb using the Spectrex detector. Essentially a repeat of event three. During this test the camera functioned properly. There was unburned residue. Deflagration was contained and extinguished by the sphere and follow-on water. Data recorded for this event are as follows:

Det event to sphere water - 28ms
Det event to water on flame - 32ms
Det event to water on table - 47ms (est)

Det event to follow-on water - 69ms
Det event to fire extinguishment - 101ms
Detector reaction times are as follows:

(1) Fire sentry - 7ms
(2) Dual Spectrum Santa Barbara - 11ms
(3) Det Tronics - 13ms
(4) Spectrex - 27ms

1 MAR 96
0940 HRS Event #1

Yellow smoke, 1/4lb using the Fire Sentry detector with RAM/LAM controller. Tom Moore was to perform the test, but problems occurred. The match activated, but did not ignite the material. EOD was called. The material was re-ignited when the match was replaced. However, the event was not recorded.

1 MAR 96
1020 HRS Event #2

Yellow smoke, 1/4lb using the Fire Sentry Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test using the same equipment and procedures previously used. There was a thin column of smoke (following sparking activity) followed by a fire of 9 inches high (4 inches wide). On this particular test the tape ejected however, the following data was retrieved:

Det event to sphere water - 31ms
Det event to water on flame - 44ms (this is an estimate)
Detector reaction times are as follows:

(1) Fire sentry - 29ms
(2) Spectrex - 29ms

The tape ejected before the other two detection times could be recorded.

Note: Because of the tape ejection, no further data could be retrieved for this test.

1 MAR 96
1300 HRS Event #3

Yellow smoke, 1/4 lb using the Fire Sentry Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test using the same equipment and procedures as before. The smoke column was dense and rose to about 14 inches high by 7 inches wide followed by a flame

obscured by smoke. The flame consisted of two separate events. The fire flame died down and rekindled. Data recorded for this event are as follows:

Det event to sphere water - 29ms
Det event to water on floor - 42ms (estimated)
Because the tape ejected, no further data could be retrieved

Detector reaction times are as follows:

(1) Fire Sentry - 27ms
(2) Dual Spectrum Santa Barbara - 28ms
The tape ejected before the other two detectors reaction time could be recorded.

12 MAR 96
1100 HRS Event #1

A test of MK-18 Project load material was scheduled for this event. However, the material had hardened and was deemed not testable. The material was destroyed by burning based upon advice from the EOD personnel conducting the tests.

13 MAR 96
1000 HRS Event #1

First Fire (Type 1) 1/4 lb using the Det Tronics Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test using the same equipment and test procedures. A small flame (about 3 inches high X 3 inches wide) was observed before reaction of the sphere. There was a lot of unburned residue on the floor and table. Data recorded for this event are as follows:

Det event to sphere water - 50ms
Det event to water on flame - 66ms
Det event to water on table - 67ms
Det event to follow-on water - 91ms
Det event to fire extinguishment - 70ms

Detects reaction times are as follows:

Because of the small size of the fire and the sphere activation, the three remaining detectors did not see the fire.

13 MAR 96
1315 HRS Event #2

First Fire (Type 1) mix, 1/4 lb using the Dual Spectrum Santa Barbara Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi

with nitrogen. Tom Moore performed the test using the same equipment and test procedures. In this event, there were two "burns". The first one (4 inches tall X 3 inches wide) was detected by the Det Tronics and Fire Sentry detectors but they were not configured to suppress the fire. The Dual Spectrum Santa Barbara detector times are based on the second event (4 inches tall by 6 inches wide)

Det event to sphere water - 77ms
Det event to water on flame - 93ms
Det event to water on table - 96ms

Follow-on water and fire extinguishment time could not be determined due to tape ejection. Detector reaction times are as follows:

(1) Det Tronics - 18ms
(2) Fire Sentry - 35ms
* (3) Dual Spectrum Santa Barbara - 76ms

* Missed the first detectable event.

13 MAR 96
1445 HRS Event #3

First Fire (Type 1) mix, 1/4 lb using the Dual Spectrum Santa Barbara Detector and RAM/LAM controller. Tom Moore performed the test using an 18 inches X 18 inches, 20 gauge pan to contain the material. Ignition, as in past tests was accomplished with an electric match and smokeless gunpowder. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. The event resulted in a flame of approximately 10 inches high and 12 inches wide with no smoke. Residue was present. Data recorded for this event was as follows:

Det event to sphere water - 73ms
Det event to water on flame - 82ms
Det event to water on table - 89ms
Det event to follow-on water - 120ms
Det event to fire extinguishment - 102ms

Detector reaction times are as follows:

(1) Det Tronics - 32ms
(2) Fire Sentry - 34ms
(3) Spectrex - 65ms
(4) Dual Spectrum - 71ms

14 MAR 96
1000 HRS Event #1

M125 Illuminate Comp, 1/4 lb using the Dual Spectrum Santa Barbara Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test using the same set up and equipment as in previous evaluations. This test was accomplished after a misfire was declared and EOD was called to replace the match. The data was not recorded on the real time video because technicians were not allowed to re-enter the room prior to the burn. After EOD reset the match there were several small popping sparks then a ball of flame of approx. 4 inches in diameter. This small ball of flame rose above the table, then broke off into several 1 inches diameter fires that burnt out. The material re-ignited into the detectable event of 8 inches tall. Residue was present. Data was recorded on the high speed video as follows:

Det event to sphere water - 14ms
Det event to water on flame - 28ms
Det event to water on table - 33ms (EST)
Det event to follow-on water - *
Det event to fire extinguishment - *

* Could not be determined due to tape ejection. Detector reaction times are as follows:

(1) Det Tronics - 10ms (from first det event)
(2) Duel Spectrum - 13ms (from second det event)

The Duel Spectrum detector did not see the first detectable event.

14 MAR 96
1350 HRS Event #2

M125 Illuminate Comp, 1/4 lb using the Dual Spectrum Santa Barbara Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore conducted the test with same set up as in previous evaluations. The high speed camera did not malfunction in this event. As the event progressed there were several small sparks with a 10 inches tall by 8 inches wide flame. Residue was present. Data recorded for this event was as follows:

Det event to sphere water - 38ms
Det event to water on flame - 47ms
Det event to water on table - 53ms
Det event to follow-on water - 83ms
Det event to fire extinguishment - 58ms

Detector reaction times are as follows:

(1) Det Tronics - 15ms
(2) Dual Spectrum Santa Barbara - 36ms
(3) Fire Sentry - 38ms

(4) Spectrex - didn't see the event prior to the extinguishment of the fire.

14 MAR 96
1530 HRS Event #3

M125 Illuminate Compound, 1/4 lb using the Spectrex Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test with the same set up as the previous evaluations. There were several small sparks and a fast rising burn. Material burned to a 12 inches tall fire by 8 inches wide. Residue was present after the burn. Data recorded for this event was as follows:

Det event to sphere water - 33ms
Det event to water on flame - 42ms
Det event to water on table - 49ms
Det event to follow-on water - 135ms
Det event to fire extinguishment - 5ms

Detector reaction times are as follows:

(1) Dual Spectrum Santa Barbara - 18ms
(2) Fire Sentry - 23ms
(3) Det Tronics - 30ms
(4) Spectrex - 32ms

22 MAR 96
1000 HRS Event #1

M125 Illuminate Compound, 1/4 lb using the Det Tronics Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test with the same set up as in previous evaluations. This was the day the camera problems previously reported were solved. There were sparks and a small (4 inches tall X 3 inches wide) fire. Residue was present after the burn. No smoke was observed. Data recorded for this event was as follows:

Det event to sphere water - 17ms
Det event to water on flame - 31ms
Det event to water on table - 33ms
Det event to follow-on water - 74ms
Det event to fire extinguishment - 39ms

The fire was extinguished or the sphere water blocked the view before the other three detectors saw the fire. The Det Tronics detector reaction time was 15ms.

22 MAR 96
1500 HRS Event #2

M125 Illuminate Compound, 1/4 lb using the Det Tronics Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test with the same set up as in previous evaluations. During this test, minor problems were experienced with the RAM/LAM controller. One electronic switching device (for the sphere) blew and was replaced by one of the follow-on water switches. In this configuration, only one solenoid operated. This would effect the follow-on water data. This problem was corrected at the end of testing on March 25th, 1996, after receipt of a new LAM module. Several sparks were present at material ignition with a flame of approximately 4 inches in diameter. Residue was present after the burn. Data recorded for this event was as follows:

Det event to sphere water - 14ms
Det event to water on flame - 29ms
Det event to water on table - 32ms
Det event to follow-on water - 107ms
Det event to fire extinguishment - 33ms

Detector reaction time was recorded only for the Det Tronics detector. The fire was extinguished or the sphere water blocked the view before the other detectors saw the fire. The Det Tronics Detector time was 12ms.

25 MAR 96
1000 HRS Event #1

First Fire mix (Type 1), 1/4 lb with the Det Tronics Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test with the same set up as in previous evaluations. Only one solenoid fired both follow-on water nozzles as previously reported. The resulting fire from the ignition was about 21 inches high and 21 inches wide. This fire appeared to be more energetic than most of the First Fire mix (Type 1) burns. There was unburned material residue on the table and floor from the burn. Data recorded for this event was as follows:

Det event to sphere water - 17ms
Det event to water on flame - 26ms
Det event to water on table - 35ms
Det event to follow-on water - 111ms
Det event to fire extinguishment - 46ms

Detector reaction times are as follows:

(1) Det Tronics - 15ms
(2) Fire Sentry - 17ms

(3) Dual Spectrum Santa Barbara - 23ms
(4) Spectrex - 23ms

26 MAR 96
1340 HRS Event #1

First Fire mix (Type 1), 1/4 lb with the Fire Sentry Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test with the same explosive lab set up as in previous evaluations. There was a 4 inches tall by 3 inches wide flame with no smoke. This fire did not sputter and throw off sparks as many of the previous First Fire mix (Type 1) burns. Residue was present after extinguishment.

Note: A new LAM module was received from Pyrotech International and installed. This unit has more electronic switching capacity and worked well after installation.

Data recorded for this event was as follows:

Det event to sphere water - 66ms
Det event to water on flame - 81ms
Det event to water on table - 83ms
Det event to follow-on water - 166ms
Det event to fire extinguishment - 98ms

Detector reaction times are as follows:

(1) Det Tronics - 39ms
(2) Fire Sentry - 64ms

Detector reaction times was recorded only for the Det Tronics and Fire Sentry units. The fire was extinguished or the sphere water blocked the view before the other detector saw the fire.

26 MAR 96
1505 HRS Event #2

First Fire mix (Type 1), 1/4 lb with the Fire Sentry Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test. The fire was visually seen from the regular video. The high speed camera revealed a 4 inches high by 4 inches wide fire with few initial sparks from the burn. This was a very slow growing fire. Residue was present. Data recorded for this event was as follows:

Det event to sphere water - 243ms
Det event to water on flame - 259ms
Det event to water on table - 260ms

Det event to follow-on water - 297ms
Det event to fire extinguishment - 269ms
Detector reaction times are as follows:
(1) Det Tronics - 51ms
(2) Fire Sentry - 241ms

The fire was extinguished or the sphere water blocked the view before the other detectors saw the fire.

27 MAR 96
1000 HRS Event #1

M206 IR flare mix, 1/4 lb using the Fire Sentry Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test with the same set up as in previous evaluations. There was a very strong energetic burn with remaining residue indicating that the system successfully stopped and extinguished the fire. Light smoke was visible after the event. Data recorded for this event was as follows:

Det event to sphere water - 6ms (est)
Det event to water on flame - 6ms (est)
Det event to water on table - unknown. Much of this water is evaporated in the process of cooling the flame before it reaches the table.
Det event to follow-on water - 104ms
Det event to fire extinguishment - 74ms
Detector reaction times are as follows:
(1) Spectrex - 4ms
(2) Fire Sentry - 5ms
(3) Dual Spectrum Santa Barbara - 6ms
(4) Det Tronics - 10ms

27 MAR 96
1145 HRS Event #2

M206 IR flare, 1/4 lb with the Det Tronics Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test with the same set up as in previous tests. There was a very strong energetic burn with remaining residue present. A difference could be heard between the sound of the sphere reaction in this event compared to the previous one. It is believed that the 4ms detection time difference between this event and event # 1 allowed more material to burn, thus the louder sound. More smoke was observed in this event than the last one. There was also a longer suppression time for this event compared to test #1. Data recorded for this event was as follows:

Det event to sphere water - 10ms
Det event to water on flame - 10ms
Det event to water on table - could not be determined. See previous note.
Det event to follow-on water - 69ms
Det event to fire extinguishment - 111ms

Detector reaction times are as follows:

(1) Spectrex - 3ms
(2) Fire Sentry - 4ms
(3) Dual Spectrum Santa Barbara - 5ms
(4) Det Tronics - 9ms

27 MAR 96
1440 HRS Event #3

M206 IR flare mix, 3/8 lb, (last test of the day) using the Dual Spectrum Santa Barbara detector. Mike Purcell performed the test using the same procedures and equipment set up before. It should be noted again that in all this series of tests the 10L sphere has been charged with 500 psi of nitrogen and 22 lbs of water. There was a rapid energetic reaction typical of M206 IR flare mix with lots of unburned residue present after the burn. Data recorded for this event was as follows:

Det event to sphere water - 6ms (estimated because of intensity of fire and difficulty seeing through it).
Det event to water on flame - 6ms
Det event to water on table - unable to measure.
Det event to follow-on water - 99ms
Det event to fire extinguishment - 238ms. It should be noted that this fire initially appeared to be out at 96 ms. However, as the high speed camera continued to roll, a small fire appeared (about 2 inches in diameter) that was present for approximately 102ms, Containment time for this fire was approximately 66ms.

Detector reaction times were as follows:

(1) Spectrex - 3ms
(2) Dual Spectrum Santa Barbara - 5ms
(3) Fire Sentry - 6ms
(4) Det Tronics - 9ms

8 APR 96
1130 HRS Event #1

First Fire mix (Type 1), 1/4 lb with the Fire Sentry Detectors and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell conducted the test using the same set procedures and equipment as in previous

evaluations. There was a fire size of about 6 inches in diameter (no smoke) that was quickly extinguished by the sphere. Data recorded for this event was as follows:

Det event to sphere water - 36ms
Det event to water on flame - 48ms
Det event to water on table - 54ms
Det event to follow-on water - 78ms
Det event to total suppression - 671ms

Detector reaction times are as follows:

(1) Det Tronics - 32ms
(2) Fire Sentry - 34ms

The fire was extinguished or the sphere water blocked the view before the other two detectors saw the fire.

Note. Det Tronics detector false alarmed several times during pre-test, but had no problems during the actual test. It was found later this same day that moisture had gotten inside the Det Tronics detector to cause the false alarms. The detector was allowed to dry and no further problems have been noted.

8 APR 96
1420 HRS Event #2

First Fire mix (Type 1), 1/4 lb with the Spectrex detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell conducted the test using the same procedures and equipment as in previous evaluations. Fire was visible to the naked eye from the regular video. There were two detectable events (small 1 inches fires) that burned separately for a short period and then merged into a single fire. The fire grew to a 5 inches tall by 8 inches wide burn. No smoke was visible and unburned residue was present on the floor and table. Follow-on water started off very sporadic with the left nozzle lagging 54ms behind the right nozzle*. Data recorded for this event was as follows:

Det event to sphere water - 151ms
Det event to water on flame - 165ms
Det event to water on table - 167ms
Det event to follow-on water - 195ms
Det event to total suppression - 178ms

Detector reaction times were as follows:

(1) Det Tronics - 33ms
(2) Fire Sentry - 42ms
(3) Dual Spectrum Santa Barbara - 106ms
(4) Spectrex - 149ms

* This happened on several events. Before each test the follow-on water lines are bled of air. To date a satisfactory explanation for variances has not been determined.

9 APR 96
1050 HRS Event #1
Restarted 1145 HRS

M125 Illuminate Composition, 1/4 lb, with the Fire Sentry Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell conducted the test using the same procedures and equipment as in previous evaluations. There was a misfire. The match went off, but the material did not burn. EOD was called and more gunpowder and a new match was added. There was sparkling of the compound followed by a thin flame of approximately 8 inches tall by 2 inches wide. Very little residue was left from the event. Data recorded for this event was as follows:

Det event to sphere water - 116ms
Det event to water on flame - 133ms
Det event to water on table - 132ms
Det event to follow-on water - 207ms
Det event to total suppression - 139ms

Detector reaction times are as follows:

(1) Det Tronics - 20ms
(2) Dual Spectrum Santa Barbara - 39ms
(3) Fire Sentry - 115ms

The Spectrex detector did not see the fire due to either fire extinguishment before detection or the detector being obscured by the water pattern from the sphere.

9 APR 96
1430 HRS Event #2

M125 Illuminate Composition, 1/4 lb with the Fire Sentry detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell conducted the test using the same procedures and equipment as in previous tests. Sparkling and a small fire were visible to the naked eye from the standard video. The high speed camera revealed a 8 inches tall by 5 inches wide fire preceded by several sparkles. The flame was quickly extinguished by the sphere. Data recorded for this event was as follows:

Det event to sphere water - 56ms
Det event to water on flame - 70ms
Det event to water on table - 73ms

Det event to follow-on water - 96ms
Det event to total suppression - 81ms

Detector reaction times were as follows:

(1) Det Tronics - 51ms
(2) Fire Sentry - 54ms
(3) Dual Spectrum Santa Barbara - 62ms

The Spectrex detector did not detect the event prior to extinguishment or blocking of view by sphere water.

9 APR 96
1545 HRS Event #3

M125 Illuminate Composition, 1/4 lb with the Spectrex detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell conducted the test. The flame attained a height of 13 inches and 3 inches wide preceded by initial sparks. There was a 21 inches tall trail of smoke, a strong burn smell, and small amount of residue. Data recorded for this event was as follows:

Det event to sphere water - 99ms
Det event to water on flame - 111ms
Det event to water on table - 117ms
Det event to follow-on water - 140ms
Det event to total suppression - 128ms

Detector reaction times are as follows:

(1) Det Tronics - 19ms
(2) Dual Spectrum Santa Barbara - 27ms
(3) Fire Sentry - 30ms
(4) Spectrex - 98ms

10 APR 96
1010 HRS Event #1

M206 IR flare mix, 1/4 lb using the Dual Spectrum Santa Barbara detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test with the same set up as in previous evaluations. There was a typical energetic reaction that saturated the high speed camera screen. Lots of unburned residue was present. There was visible smoke above the table after the reaction. Data recorded for this event was as follows:

Det event to sphere water - 15ms
Det event to water on flame - 15ms (est)

Det event to water on table - unknown. Much of the water is evaporated in the process of cooling this very energetic flame before it reaches the table.

Det event to follow-on water - 108ms

Det event to fire extinguishment - 157ms (Fire was contained at 68ms)

Detector reaction times are as follows:

(1) Spectrex - 11ms
(2) Fire Sentry - 12ms
(3) Dual Spectrum Santa Barbara - 14ms
(4) Det Tronics - 15ms

10 APR 96
1300 HRS Event #2

M206 IR flare mix, 1/4 lb using the Dual Spectrum Santa Barbara detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test with the same test set up as in previous evaluations. A violent reaction producing lots of smoke and unburned residue. Data recorded for this event was as follows:

Det event to sphere water - 7ms
Det event to water on flame - 7ms (est)
Det event to water on table - unknown.
Det event to follow-on water - 58ms
Det event to fire extinguishment - 102ms (Fire was contained at 65ms)

Detector reaction times are as follows:

(1) Spectrex - 4ms
(2) Dual Spectrum Santa Barbara - 6ms
(3) Fire Sentry - 7ms
(4) Det Tronics - 11ms

10 APR 96
1450 HRS Event #3

M206 IR flare mix, 1/4 lb using the Fire Sentry detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell conducted the tests with the same procedures and set up as in previous evaluations. During this test the left follow-on water switch (nozzle switch) lost contact before the test. Lost data from the left nozzle. This was a typical M206 reaction where all detectors saw the event. Data recorded for this event was as follows:

Det event to sphere water - 7ms
Det event to water on flame - 7ms (est)
Det event to water on table - could not be determined.

Det event to follow-on water - 54ms
Det event to fire extinguishment - 87ms (Fire contained in 44ms)
Detector reaction times are as follows:

(1) Spectrex - 6ms
(2) Fire Sentry - 6ms
(3) Dual Spectrum Santa Barbara - 8ms
(4) Det Tronics - 12ms

16 APR 96
1100 HRS Event #1

MK25 Marine Locate Starter compound, 1/4 lb using the Fire Sentry detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test with the same test set up and procedures as in previous tests. Small flame and smoke visible to the naked eye. Small fire ball (2 inches diameter) that died down and then rekindled into 5 inches X 3 inches (wide) flame. Lots of unburned residue. Data recorded for this event was as follows:

Det event to sphere water - 17ms
Det event to water on flame - 33ms
Det event to water on table - 35ms
Det event to follow-on water - 59ms
Det event to total suppression - 41ms
Detector reaction times are as follows:

(1) Det Tronics - unit alarmed 11ms after the first fire ball burned out.
(2) Fire Sentry - 16ms (from re-kindled flame)
(3) Dual Spectrum Santa Barbara - 21ms (from re-kindled flame)
(4) Spectrex - The flame was out or blocked by the spray water before the unit detected the fire.

16 APR 96
1345 HRS Event #2

MK25 Marine Locate Starter compound, 1/4 lb using the Fire Sentry detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test using the same test set up and procedures as in previous tests. Small flame and small amount of smoke visible to the naked eye. The high speed camera revealed a small 1 inches diameter ball of flame that lingered, then propagated into a 6 inches tall by 3 inches wide flame. Unburned residue was present after the test but no smoke. Data recorded for this event was as follows:

Det event to sphere water - 36ms
Det event to water on flame - 51ms (est)

Det event to water on table - 53ms
Det event to follow-on water - 77ms
Det event to total extinguishment - 57ms

Detector reaction times are as follows:

(1) Det Tronics - 33ms
(2) Fire Sentry - 35ms
(3) Spectrex and Dual Spectrum Santa Barbara did not see the fire prior to extinguishment or the view being blocked by sphere water.

16 APR 96
1510 HRS Event #3

MK25 Marine Locate Starter compound, 1/4 lb with the Spectrex detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test. The igniting match popped up several inches. A fire ball started at about 1 inches in diameter and grew into a 6 1/2 inches tall by 5 inches wide fire. Unburned residue was present after the burn. Data recorded for this event was as follows:

Det event to sphere water - 56ms
Det event to water on flame - 70ms
Det event to water on table - 73ms
Det event to follow-on water - 100ms
Det event to total suppression - 82ms

Detector reaction times are as follows:

(1) Fire Sentry - 37ms
(2) Det Tronics - 38ms
(3) Dual Spectrum Santa Barbara - 40ms
(4) Spectrex - 55ms

17 APR 96
0930 HRS Event #1

MK25 Marine Locate Starter compound, 1/4 lb with the Dual Spectrum Santa Barbara detector. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the tests using an 18 inches X 18 inches 20 gauge steel pan. Ignition was accomplished by an electric match and smokeless gunpowder. Event started with smoke and small sparkling fire that propagated into a 7 1/2 inches tall by 4 inches wide fire. Unburned residue was present after extinguishment. Data recorded for this event was as follows:

Det event to sphere water - 20ms
Det event to water on flame - 34ms
Det event to water on table - 37ms
Det event to follow-on water - 117ms

Det event to total suppression - 41ms

Detector reaction times are as follows:

(1) Det Tronics - 13ms
(2) Fire Sentry - 14ms
(3) Dual Spectrum Santa Barbara - 18ms
(4) Spectrex did not see the fire.

17 APR 96
1300 HRS Event #2

MK25 Marine Locate Starter compound, 1/4 lb with the Det Tronics Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test with the same set up and procedures as before. Sparkling fire ball of approximately 1 inches. The detectable event next started about 2 inches from the table top. The fire grew to 6 inches tall and 5 inches wide. The follow-on water for reasons unknown was considerably faster. Lots of unburned residue was present. Data recorded for this event was as follows:

Det event to sphere water - 18ms
Det event to water on flame - 33ms
Det event to water on table - 35ms
Det event to follow-on water - 60ms
Det event to total suppression - 43ms

Detector reaction times are as follows:

(1) Fire Sentry - 15ms
(2) Det Tronics - 17ms
(3) Dual Spectrum Santa Barbara - 22ms
(4) Spectrex did not see event.

18 APR 96
1045 HRS Event #1

Red lead mix, 1/4 lb with the Fire Sentry Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mr. Monroe Roberts of Fire Sentry was on site for these tests. Mike Purcell performed the test. The reaction was slow and not as energetic as other red lead burns. The flame was only about 5 inches tall and 5 inches wide. At first it was believed that the material was loosing its strength because of shelf life time. However, this was not the case as subsequent red lead tests were as energetic as ever. Data recorded for this event was as follows:

Det event to sphere water - 29ms
Det event to water on fire - 42ms
Det event to water on table - 46ms

Det event to follow-on water - 68ms
Det event to total suppression - 53ms
Detector reaction times are as follows:
(1) Fire Sentry - 27ms
(2) Spectrex - 33ms
(3) Dual Spectrum Santa Barbara - 36ms
(4) The Det Tronics detector did not see the event although this was a clear detectable event.

18 APR 96
1345 HRS Event #2

Red lead, 1/4 lb using the Fire Sentry detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test using the same procedures and set up as before. Monroe Roberts of Fire Sentry was observing the tests this day. The reaction was somewhat slower than other red lead tests producing a 5 inches tall by 8 inches wide flame. The event was easily defined and clear of smoke. Data recorded for this event was as follows:

Det event to sphere water - 17ms
Det event to water on flame - 31ms
Det event to water on table - 34ms
Det event to follow-on water - 103ms
Det event to fire extinguishment - 76ms (Fire was contained in 37ms)
Detector reaction times are as follows:
(1) Fire Sentry - 15ms
(2) Spectrex - 19ms
(3) Dual Spectrum Santa Barbara - 20ms
(4) Det Tronics - 23ms

3 MAY 96
1300 HRS Event #1

Red lead, 1/4 lb, using the Dual Spectrum Santa Barbara detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test. This was a typically highly energetic reaction as has been seen with other powerful red lead burns. No smoke. The flame totally saturated the camera as has been typical of red lead deflagrations. Unburned residue was visible on the table and floor. Data recorded was as follows:

Det event to sphere water - 9ms
Det event to water on flame - 9ms (est)
Det event to water on table - could not be determined
Det event to follow-on water - 51ms
Det event to total suppression - 84ms (Fire was contained in 34ms)

Detector reaction times are as follows:

(1) Spectrex - 7ms
(2) Fire Sentry - 7ms
(3) Dual Spectrum Santa Barbara - 8ms
(4) Det Tronics - 12ms

3 MAY 96
1450 HRS Event #2

Red lead, 1/4 lb using the Det Tronics detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test using the same procedures and test set up as before. The fire saturated the camera as is typical of red lead events. During this test, the technician taped a piece of 12 inches X 12 inches tissue paper to the base of the lexan screen to observe if it had any burn marks from the test. After the burn, no sign of scorching occurred. Data recorded for this event was as follows:

Det event to sphere water - 13ms (est)
Det event to water on flame - 13ms (est)
Det event to water on table - could not be determined with equipment available.
Det event to follow-on water - 52ms
Det event to total suppression - 69ms (Fire was contained in 40ms)

Detector reaction times are as follows:

(1) Fire Sentry - 6ms
(2) Dual Spectrum Santa Barbara - 8ms
(3) Spectrex - 8ms
(4) Det Tronics - 12ms

6 MAY 96
1015 HRS Event #1

Green smoke, 1/4 lb using the Det Tronics detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test. A small column (5 inches tall) of smoke was visible to the naked eye. The high speed camera revealed smoke and a small ball of flame about 4 inches in diameter. Small amount of residue was present after the burn. It appears that some of the remaining residue is being absorbed by the water (water soluble). Data recorded for this event was as follows:

Det event to sphere water - 40ms
Det event to water on flame - 55ms
Det event to water on table - 57ms
Det event to follow-on water - 82ms

Det event to fire suppression - 61ms (Fire containment time was 58ms)
Detector reaction times are as follows:

(1) Det Tronics - 38ms
(2) Fire Sentry - 48ms

Dual Spectrum Santa Barbara and Spectrex did not see the fire prior to extinguishment or water blocking their line of sight.

6 MAY 96
1300 HRS Event #2

Green smoke, 1/4 lb using the Dual Spectrum Santa Barbara detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test. Rising smoke and a 1 inches fire visible to the naked eye. The higher speed camera revealed a 13 inches high smoke stack and a 11 inches tall by 8 inches wide fire before suppression. A clear detectable event. Data recorded for this event was as follows:

Det event to sphere water - 62ms
Det event to water on flame - 73ms
Det event to water on table - 81ms
Det event to follow-on water - 121ms
Det event to fire extinguishment - 85ms (Fire was contained in 79ms)

Detector reaction times are as follows:

(1) Fire Sentry - 30ms
(2) Dual Spectrum Santa Barbara - 61ms
(3) Det Tronics - 68ms
(4) Spectrex - did not react to the event. See previous comments.

6 MAY 96
1500 HRS Event #3

Green smoke, 1/4 lb with the Spectrex detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test with the same set up as in previous evaluations. A flame and smoke were visible to the naked eye. The high speed camera revealed sparkling, then a 1 1/2 inches fire ball that lingered followed by another 1 inches fire ball that merged into the first flame. The flame grew to 11 inches tall by 8 inches wide. Very little residue remained. It apparently is absorbed into the water. Data recorded for this event was as follows. All times were based on the second fire ball:

Det event to sphere water - 143ms
Det event to water on flame - 155ms
Det event to water on table - 162ms

Det event to follow-on water - 291ms
Det event to total fire suppression - 167ms (Contained fire in 160ms)

Detector reaction times are as follows:

(1) Det Tronics - 27ms
(2) Fire Sentry - 34ms
(3) Duel Spectrum Santa Barbara - 51ms
(4) Spectrex - 141ms

7 MAY 96
1000 HRS Event #1

Yellow smoke, 1/4 lb with the Spectrex detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test with the same set up and procedures as before. Lots of smoke was visible during the burn. Smoke rose up to the sphere with a small flame visible to the naked eye. The high speed camera revealed a small flame (1/2 inches in diameter) that lingered for approximately 500ms before dying. The Det Tronics detector saw this first event. Sparkling occurred followed by large sporadic flashes that lasted about 5ms each. This grew into a 21 inches tall by 18 inches fire that was detected and extinguished by the sphere. As the follow-on water started to flow the left nozzle sputtered. The right nozzle did not come on until 118ms later. Both valves were checked after the event and no problems could be found. Bottom line however, is that follow-on water has always come on before the sphere emptied providing excellent backup cooling. Data recorded for this event was as follows:

Det event to sphere water - 118ms*
Det event to water on flame - 127ms
Det event to water on table - 136ms
Det event to follow-on water - 190ms
Det event to total fire extinguishment - 141ms (Fire was contained in 135ms)

* Estimated smoke rose to sphere and hampered visual high speed camera observations.

Detector reaction times were as follows:

(1) Det Tronics - 20ms (based on the first detectable event)
(2) Duel Spectrum Santa Barbara - 46ms (second event)
(3) Fire Sentry - 95ms second event (may have been hampered by smoke)
(4) Spectrex - 117ms

Note: There was a small amount of residue that was splashed upon the test room walls. Little smoke and little odor.

7 MAY 96
1300 HRS Event #2

Yellow smoke, 1/4 lb using the Det Tronics detector. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test. There were small sparkles and a single detectable event. The smoke rose to 26 inches followed by sparkles and a fire of approximately 13 inches tall and 8 inches wide. Residue (small amount) was present with no smoke after the fire. Moderate odor. Data recorded for this event was as follows:

Det event to sphere water - 50ms
Det event to water on flame - 61ms
Det event to water on table - 68ms
Det event to follow-on water - 148ms
Det event to total fire extinguishment - 73ms (Fire was contained in 69ms)

Detector reaction times were as follows:

(1) Fire Sentry - 34ms
(2) Duel Spectrum Santa Barbara - 43ms
(3) Det Tronics - 49ms
(4) Spectrex - did not detect the fire. Fire was suppressed before the detector could react, or sphere water blocked it's view.

7 MAY 96
1445 HRS Event #3

Yellow smoke, 1/4 lb using the Det Tronics detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test. Easily defined single detectable event. There were sparkles followed by a 25 inches column of smoke and a 18 inches high by 8 inches wide flame. This was a slow growing fire. A small fire and lots of smoke was visible to the naked eye. Data recorded for this event was as follows:

Det event to sphere water - 215ms
Det event to water on flame - 224ms
Det event to water on table - 234ms
Det event to follow-on water - 335ms
Det event to fire suppression - 237ms (Fire was contained in 233ms)

Detector reaction times were as follows:

(1) Dual Spectrum Santa Barbara - 183ms
(2) Fire Sentry - 193ms
(3) Spectrex - 199ms
(4) Det Tronics - 213ms

Note: Small amount of residue present after the test, no smoke, and a moderate odor.

8 MAY 96
0945 HRS Event #1

Green smoke, 1/4 lb using the Det Tronics detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test. The fire was characterized by sparkling and a flame that grew to 6 inches tall X 5 inches wide. The smoke preceding the fire rose to about 11 inches. Very little residue was present after the burn with slight odor detectable. Data recorded for this event was as follows:

Det event to sphere water - 46ms
Det event to water on flame - 58ms
Det event to water on table - 61ms
Det event to follow-on water - 84ms
Det event to total fire extinguishment - 66ms (Fire was contained in 61ms)

Detector reaction times were as follows:

(1) Det Tronics - 44ms
(2) Fire Sentry - 44ms

Not detected by the Dual Spectrum Santa Barbara or Spectrex detector. See previous comments.

8 MAY 96
1050 HRS Event #2

Green smoke, 1/4 lb using the Dual Spectrum Santa Barbara detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the evaluation with the same set-up as in previous tests. The high speed camera revealed sparkling and a single detectable fire that grew to 8 inches tall and 8 inches wide. The fire was preceded by a column of dense green smoke that grew to about 8 inches tall. Data recorded for this event was as follows:

Det event to sphere water - 51ms
Det event to water on flame - 65ms
Det event to water on table - 69ms
Det event to follow-on water - 92ms
Det event to total fire extinguishment - 75ms (Fire was contained at 70ms)

Detector reaction times were as follows:

(1) Fire Sentry - 42ms
(2) Det Tronics - 49ms
(3) Dual Spectrum Santa Barbara - 50ms
(4) Spectrex - 55ms

Note: Very little residue present after fire, no smoke and slight odor.

8 MAY 96
1315 HRS Event #3

Green smoke, 1/4 lb Spectrex detector with RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test. There was a small low fire with lots of smoke visible to the naked eye. The high speed camera revealed a 15 inches high smoke column and a small 2 inches ball of fire that was not initially detected by any of the detectors. The detectable fire grew from sparkles to a 10 inches tall by 12 inches wide flame. Data recorded for this event was as follows:

Det event to sphere water - 105ms
Det event to water on flame - 117ms
Det event to water on table - 125ms
Det event to follow-on water - 140ms
Det event to total extinguishment - 129ms (Contained fire in 121ms)

Detector reaction times were as follows:

(1) Dual Spectrum Santa Barbara - 76ms
(2) Det Tronics - 92ms
(3) Fire Sentry - 97ms
(4) Spectrex - 103ms

Note: Very little residue, no smoke after the test and a slight odor.

8 MAY 96
1425 HRS Event #4

Green smoke, 1/4 lb with the Fire Sentry detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test. There was a small visible to the eye fire with smoke rising to about 7 inches. The high speed camera revealed small sparkles leading to a clear detectable flame of 6 1/2 inches high by 4 inches wide. There was a small amount of residue, no smoke after the burn and no odor. Data recorded for this event was as follows:

Det event to sphere water - 43ms
Det event to water on flame - 58ms
Det event to water on table - 60ms
Det event to follow-on water - 82ms
Det event to total extinguishment - 67ms (Fire was contained in 61ms)

Detector reaction times were as follows:

(1) Fire Sentry - 41ms
(2) Det Tronics - 50ms

The Dual Spectrum Santa Barbara and Spectrex detector did not see the fire before extinguishment or water from the sphere blocking their view.

9 MAY 96
0940 HRS Event #1

MK25 Marine Locate starter composition, 1/4 lb with the Fire Sentry detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test. The burn resembled a small volcano, erupting sparkles from a central source. One of several 1/2 inches fire balls was projected upward then propagated into the detectable event. The fire was 6 1/2 inches tall by 4 inches wide. There was lots of residue, no smoke and moderate odor present after the event. Data recorded for this event was as follows:

Det event to sphere water - 14ms
Det event to water on flame - 26ms
Det event to water on table - 30ms
Det event to follow-on water - 51ms
Det event to total extinguishment - 33ms

Detector reaction times were as follows:

(1) Fire Sentry - 12ms
(2) Dual Spectrum Santa Barbara - 15ms

9 MAY 96
1110 HRS Event #2

MK25 Marine Locate composition, 1/4 lb with the Det Tronics Detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test. Small amount of fire and smoke were seen by the naked eye. Again the event resembled a small volcano. There were initial sparks, a 9 inches column of smoke and an eventual detectable event of approximately 11 inches tall and 6 inches wide. There was lots of residue, no smoke and moderate odor present at the end of the fire. Data recorded for this event was as follows:

Det event to sphere water - 21ms
Det event to water on flame - 31ms
Det event to water on table - 37ms
Det event to follow-on water - 59ms
Det event to total extinguishment - 47ms (Contained in 41ms)

Detector reaction times were as follows:

(1) Fire Sentry - 13ms
(2) Dual Spectrum Santa Barbara - 15ms
(3) Spectrex - 17ms
(4) Det Tronics - 19ms

9 MAY 96
1340 HRS Event #3

MK25 Marine Locate composition, 1/4 lb with the Dual Spectrum detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test. Smoke and a very small flame were visible to the naked eye. The high speed camera revealed considerable sparkling and a flame that started about an inch above the test table. The sparks this time did not erupt in a volcanic manner. The fire grew to about 8 inches tall by 5 inches wide. There was lots of remaining residue, no smoke and moderate odor at the end of the fire. Data recorded for this event was as follows:

Det event to sphere water - 65ms
Det event to water on flame - 77ms
Det event to water on table - 81ms
Det event to follow-on water - 103ms
Det event to total extinguishment - 87ms (Fire was contained in 81ms)

Detector reaction times were as follows:

(1) Det Tronics - 40ms
(2) Fire Sentry - 61ms
(3) Dual Spectrum Santa Barbara - 63ms
(4) Spectrex did not see the event. See previous comments.

9 MAY 96
1500 HRS Event #4

MK25 Marine Locate composition, 1/4 lb using the Spectrex detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore performed the test. Smoke and a very small flame were visible to the naked eye. The high speed camera revealed a small volcanic like eruption producing several sparks that grew into a 10 1/2 inches tall by 6 inches fire. Lots of residue remained on the test table with no smoke visible after the event and a moderate odor. Data recorded for this event was as follows:

Det event to sphere water - 41ms
Det event to water on flame - 51ms
Det event to water on table - 58ms
Det event to follow-on water - 81ms
Det event to total extinguishment - 64ms (Fire was contained in 61ms)

Detector reaction times were as follows:

(1) Dual Spectrum Santa Barbara - 25ms
(2) Det Tronics - 31ms
(3) Fire Sentry - 37ms
(4) Spectrex - 38ms

21 MAY 96

1040 HRS Event #1

Yellow smoke, 1/4 lb with Spectrex detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test. There was a 19 inches tall smoke column (no visible flame) visible to the naked eye. The high speed camera revealed a clear detectable 19 inches tall by 9 inches wide fire. Sparkling of the material occurred before the fire with small intermediate ignition lasting about 5ms each. A small amount of unburned residue was present with no remaining smoke after the event. A distinct odor was present after the burn. Data recorded for this event was as follows:

Det event to sphere water - 37ms
Det event to water on flame - 41ms
Det event to water on table - 56ms
Det event to follow-on water - 134ms
Det event to total extinguishment - 61ms (Fire was contained in 55ms)

Detector reaction times were as follows:

(1) Dual Spectrum Santa Barbara - 18ms
(2) Fire Sentry - 26ms
(3) Det Tronics - 28ms
(4) Spectrex - 35ms

21 MAY 96
1330 HRS Event #2

Yellow smoke, 1/4 lb with the Dual Spectrum Santa Barbara detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test. A 7 inches column of smoke was visible to the naked eye. There was an 8 inches tall by 6 inches wide flame preceded by sparkles. A clear detectable event. Residue was present and was seen to splatter over the table. It appears there is a lot of the residue being absorbed into the remaining water (lots of yellow water afterwards). There was a distinct odor present after the test. Data recorded for this event was as follows:

Det event to sphere water - 26ms
Det event to water on flame - 35ms
Det event to water on table - 42ms
Det event to follow-on water - 129ms
Det event to total extinguishment - 49ms (Fire was contained in 46ms)

Detector reaction times were as follows:

(1) Det Tronics - 17ms
(2) Fire Sentry - 19ms
(3) Dual Spectrum Santa Barbara - 24ms

(4) Spectrex - The fire was extinguished before the detector saw the fire or sphere water blocked its view. There is no doubt that the detector would have seen the fire if the suppression system had not been previously activated by another detector.

21 MAY 96
1455 HRS Event #3

Yellow smoke, 1/4 lb with the Fire Sentry detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Tom Moore was the EOD technician conducting the tests. Smoke barely visible to the naked eye. No flame was seen. The high speed camera revealed the material bulged, sparkled and eventually produced a 10 1/2 inches high by 6 inches wide flame. Smoke was barely visible even on the high speed camera. Small amount of residue was present but no smoke was seen after the event. Data recorded for this event was as follows:

Det event to sphere water - 25ms
Det event to water on flame - 33ms
Det event to water on table - 43ms
Det event to follow-on water - 125ms
Det event to fire extinguishment - 49ms (Fire was contained in 44ms)

Detector reaction times were as follows:

(1) Dual Spectrum Santa Barbara - 16ms
(2) Fire Sentry - 23ms
(3) Det Tronics - 26ms
(4) Spectrex - 27ms

22 MAY 96
1330 HRS Event #1

M206 IR flare mix, 1/4 lb with the Spectrex detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test. This was a typical highly energetic M206 event. No smoke or fire is visible to the naked eye. Smoke and large amounts of unburned residue was present after the event. The high speed camera was completely saturated with the flame up until containment of the fire is achieved. Data recorded for this event was as follows:

Det event to sphere water - 5ms (est)
Det event to water on flame - 5ms (est)
Det event to water on table - could not be determined
Det event to follow-on water - 114ms
Det event to total extinguishment - 106ms (Fire was contained in 56ms)

Detector reaction times were as follows:

(1) Spectrex - 4ms
(2) Fire Sentry - 5ms
(3) Dual Spectrum Santa Barbara - 6ms
(4) Det Tronics - 11ms

This test was a good example of the speed of this system as documented by large amounts of unburned residue on the table, walls of the facility, lexan table, video screen, etc. See video.

22 MAY 96
1515 HRS Event #2

M206 IR Flare mix, 1/4 lb with the Det Tronics detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test. This was a typical highly energetic M206 event. No smoke or fire is visible to the naked eye during the burn. Large amounts of smoke and residue remained after the event and a strong odor of the burnt material. Data recorded for this event was as follows:

Det event to sphere water - 11ms (est)
Det event to water on flame - 11ms (est)
Det event to water on table - unknown. Could not be determined by the high speed camera or from amount evaporating from this highly energetic heat generating event.
Det event to follow-on water - 129ms (based on nozzle switches)
Det event to total extinguishment - 73ms (The fire was contained in 57ms)

Detector reaction times were as follows:

(1) Spectrex - 3ms
(2) Dual Spectrum Santa Barbara - 6ms
(3) Fire Sentry - 6ms
(4) Det Tronics - 10ms

Note: The f-stop setting on the high speed camera was set high for this test. Extinguishment time was therefore difficult to determine and cannot be accurately compared to other tests in this study.

23 MAY 96
1025 HRS Event #1

M125 Illuminate composition, 1/4 lb with the Det Tronics detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test. There were sparks and a small amount of smoke visible to the naked eye. The high speed camera revealed sparkling, a thin stream of upward

moving gasses resulting in a fire that grew 10 inches tall by 7 inches wide starting 6 inches above the table. Lots of residue, no smoke and a minute smell of burnt material were present after the burn. Data recorded for this event was as follows:

Det event to sphere water - 15ms
Det event to water on flame - 23ms
Det event to water on table - 30ms
Det event to follow-on water - 111ms
Det event to total extinguishment - 36ms (Fire was contained in 31ms)

Detector reaction times were as follows:

(1) Dual Spectrum Santa Barbara - 10ms
(2) Det Tronics - 13ms
(3) Fire Sentry - 16ms
(4) Spectrex - 18ms

23 MAY 96
1340 HRS Event #2

M125 Illuminate compound, 1/4 lb with the Fire Sentry detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike Purcell performed the test. There were sparks and a small amount of smoke visible to the naked eye. The high speed camera revealed an event very similar to the previous one with super hot gas spiraling out of the sparks and developing into a detectable event approximately 4 inches off the table. The fire grew to an approximate size of 6 inches tall and 5 inches wide. There was lots of residue remaining, no smoke and a slight odor. Data recorded for this event was as follows:

Det event to sphere water - 24ms
Det event to water on flame - 36ms
Det event to water on table - 39ms
Det event to follow-on water - 117ms
Det event to total extinguishment - 47ms (Fire was contained in 42ms)

Detector reaction times were as follows:

(1) Det Tronics - 16ms
(2) Dual Spectrum Santa Barbara - 17ms
(3) Fire Sentry - 22ms
(4) Spectrex - Did not see the fire. See previous comments.

23 MAY 96
1540 HRS Event #3

First Fire mix (Type 1), 1/4 lb, with the Det Tronics detector and RAM/LAM controller. The 10L sphere with 22 lbs of water was pressurized to 500 psi with nitrogen. Mike

Purcell performed the test. The fire from this event only attained a size of approximately 1 1/2 inches diameter before extinguishment. There were copious amounts of residue remaining on the table and floor and no visible smoke after the event. Data recorded for this event was as follows:

Det event to sphere water - 29ms
Det event to water on flame - 44ms
Det event to water on table - 44ms
Det event to follow-on water - 121ms
Det event to total extinguishment - 54ms (Fire was contained in 48ms)

Only the Det Tronics detector saw this fire - reaction time was 27 ms.

APPENDIX 4
DEFINITIONS

Contained Flame Time. The time that suppression water surrounds the flame preventing further flame propagation.

Controller Signal Output. The instant that an electronic controller system issues a suppression discharge signal.

Detectable Event. The first indication of a visible fire ball generated by the ignited material, as viewed on the high speed camera, that should be "seen" by a flame detector.

Detection Response Time (Flame Detection Time). The instant that a optical flame detector issues a fire alarm signal. Detection response time is measured from the detectable event.

Event Initiation. Ignition time of the electric match that started the event.

False Activation. Unwanted discharge of a suppression deluge system caused by a mechanical or electrical malfunction or by a detection system false alarm.

False Alarm. An alarm signal issued by a optical flame detector when no flame is present. A false alarm is most often caused by radiation emissions in the same spectral band that the flame detector uses to detect fires.

Flame Extinguishment. The time from the detectable event until the visible flame is no longer present, as viewed on the high speed camera.

Follow-On Water System. Dual nozzle pressurized water which provides additional cooling and extinguishment during and after sphere discharge.

Nozzle Discharge Time. The instant that water exits the nozzle

Nozzle Response Time. The time from Controller Signal Output until water discharge.

Sphere Discharge Time. The instant that water exits the high rate discharge sphere.

Sphere Response Time. The time from Controller Signal Output until sphere discharge.

Water on Flame. The time from the detectable event until the water discharged from the suppression system reaches the visible flame.

Water on Table Top. The time from the detectable event until the water discharged from the suppression system reaches the surface of the table where the material is burning.